A SCHEME FOR THE UNIFORM MAPPING AND MONITORING OF EARTH RESOURCES AND ENVIRONMENTAL COMPLEXES

An Assessment of Natural Vegetation, Environmental, and Crop Analogs

Charles E. Poulton and Robin I. Welch
Earth Satellite Corporation
2150 Shattuck Avenue
Berkeley, California 94704

July 1975
Final Report, Type III

Prepared for
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

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EARTH SATELLITE CORPORATION (EarthSat)
7222 47th St. (Chevy Chase), Washington, D.C. 20015
2150 Shattuck Avenue, Berkeley, California 94704
(301) 652-7130 (415) 845-5140

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16. Abstract
A study was performed to develop and test a procedure for the uniform mapping and monitoring of natural ecosystems in the semi-arid and wooded regions of the Sierra-Lahontan and Colorado Plateau areas, and for the estimating of rice crop production in the Northern Great Valley (California) and the Louisiana Coastal Plain. ERTS-1 and high-flight and low-flight aerial photos were used in a visual photo interpretation scheme to identify vegetation complexes, map acreages, and evaluate crop vigor and stress. From these data an evaluation was made of the usefulness of various dates, scales, and spectral bands of coverage. A uniform hierarchical legend system was thoroughly tested. A series of photo interpretation tests and image feature measurements are reported.

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PREFACE

The concepts and objectives of this investigation were the outgrowth of developmental earth resources research by the authors and their associates using simulated space photography, Gemini IV and Apollo VI and IX space photographs. These materials were used together with support aircraft photography in early experiments to inventory natural vegetation and estimate wheat and rice production. This new investigation was designed to contribute to the refinement of a scheme for the uniform mapping and monitoring of earth resources, environmental conditions, and important food crops through the interpretation of ERTS-1 and support aircraft imagery. Central focus was on natural vegetation analogs and on rice as one of the world's most important food crops. Our hypothesis is that analogous vegetations (natural and food crops) and environmental complexes should have sufficiently analogous remote sensing signatures that they could be recognized in each of many regions from subject/image relationships worked out in a few representative regions. The three natural vegetation objectives and three rice crop objectives may be paraphrased as follows:

> Further test and refine a uniform ecological legend for making natural resource inventories in two regions of the United States and identify the potentialities and limitations of the legend for ERTS-1 interpretation.
>
> Determine the kinds of natural vegetation analogs that can and cannot be interpreted from the conventional photographic image products of the ERTS-1 system.
>
> Develop, test, and specify a practical procedure and system for uniform mapping and monitoring of natural ecosystems and environmental complexes by the use of space acquired imagery.

Determine the dates of coverage, spatial and spectral resolution characteristics of Skylab EREP data and aerial support photos needed for rice crop identification.

Determine the spatial and spectral resolution characteristics of Skylab EREP data and aerial support photos needed for evaluating plant stress and crop vigor conditions leading to yield estimation.

Define the dates of coverage needed, the photo interpretation procedures and the data reduction methods needed to provide accurate rice yield estimates from Skylab and supporting aerial photography.

Image delivery and quality problems together with cloudy weather compounded to cause adverse impacts on cost of the work, maintenance of schedules and, in some instances, on the attainment of objectives. The southern Coastal Plain Test Site in Louisiana had to be discontinued after a considerable investment in ground truth and low-level, support photography. Excellent satellite imagery and generally adequate aircraft photography at the necessary dates were obtained over the remaining test areas. Project work was essentially discontinued in December 1973 because of lack of funds when an overrun was requested. At that time we were prepared to begin comprehensive interpretation testing, but this work and the intensive evaluation of all images to be used in the yield analysis of rice had to be held in abeyance. On 29 August 1974 we were awarded limited additional funds adequate to prepare a final report, essentially on work completed prior to discontinuation of activity. As a partial substitute for the deficiencies this delay and funding level

forced on the project, we have reinterpreted and slightly expanded on some work from an ERTS-1/Skylab comparative study which we conducted with other NASA funds. We evaluated this latter work more specifically in terms of the objectives and goals of this experiment and also to give some indication of the interpretability of specified vegetation and crop analogs. In addition, in our subjective assessment of image interpretation and feasibility of the analog concept, we have also drawn on experience of our staff in the operational use of ERTS-1 on other vegetation inventory projects.

Work prior to shutdown did, however, contribute significantly to most of the objectives, and thus showed that the working hypothesis is sound, the legend system is particularly effective for the interpretation of ERTS imagery, and the analog concept provides a sound basis for interregional image interpretation. Results also showed that, for different kinds of natural vegetation subjects or environmental conditions and some crop types, the hierarchical level of classification that is interpretable does change between the second and fifth levels as one moves from ecosystem between the two regions. Our conclusions may be summarized as follows:

1. The vegetation analog concept is a valid concept for intra- and interregional mapping of natural vegetation.

2. The uniform legend system is generally applicable for ERTS-1 interpretation at second to fourth levels depending on the subject.

3. The least specific identification of natural vegetational subjects is possible in arid and saline-arid environments where vegetation is sparse and the soil background overrides the vegetation image component.

4. Further developmental work to quantitatively characterize interregional and global analogs is justified. Particularly in developing nations, scientists are frequently called upon to perform useful interpretations with a minimum of ground information and often without supporting aircraft photography. In this setting, both the legend system and the analog concept have been found particularly useful by EarthSat scientists working with the concepts on other operational projects.

5. Interpretability of rice from ERTS-1 imagery is consistent and predictable, but mapping and acreage determinations from ERTS alone is difficult and poses certain significant errors and uncertainties.

6. Multidate analysis is essential for accurate identification of rice from ERTS-1 and use of appropriate multidate aircraft photography permits accurate acreage determination and assessment of yield-related physical and physiological factors within fields.

7. The primary role of ERTS in an operational rice production inventory would be the detection (a) of rice growing areas with little-known regions as an initial stratification for sampling, and (b) of field-specific information in well-known areas where field sizes are 10 to 20 acres (4 to 8 ha.) and above.

Recommendations based on the work we have done may be summarized as follows:

1. For existing ERTS-1 data (spot-checked and supplemented if necessary by ERTS-B) a concerted effort should be made to quantify interregional North American, analogs of natural vegetation and environmental complexes (ecosystems) and key food crop types. Quantification should be by digital tape analysis of the multispectral signatures at key stages of development.

2. To aid people who must ocularly interpret ERTS images, sets of ERTS image interpretation keys should be assembled and organized according to our uniform legend system on a regional or ecological province and appropriate multidate basis.

3. The study in the Northern Great Valley Test Area should be completed to apply the ERTS-type system in a multistage sampling scheme to fully test the accuracy of rice yield prediction against harvest crop yields and USDA statistical records.

4. ERTS digital tape analysis should be more widely evaluated for crop identification, acreage determination and especially for evaluation of vigor and stress factors.

5. For regions of high cloud incidence, as the Louisiana Coastal Plain, a study should be conducted to determine sequential spacing of overflights required to ensure coverage at critical periods in a typical year. Weather satellite data analysis should provide the essential information for analysis. Yield prediction of food crops is sufficiently important to warrant substantially greater attention to problems that stand in the way of full implementation of extensive crop forecasting programs for key food crops like rice, wheat, and maize.

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1.0 INTRODUCTION

The rationale which has led to our conducting the present study can be quite simply expressed in a six-part statement as follows: (1) because the global population is rapidly increasing, the global demand for food, fodder, fiber and minerals also is rapidly increasing; (2) the increased demand is further accentuated by mankind's insistence (at all economic levels and essentially on a global basis) for higher standards of living, thereby increasing the *per capita* demand for earth resources and products; (3) this increased *demand* is occurring at a time when a decreased supply of certain of the earth resources required to produce food, fodder, fiber and minerals also is occurring and when the overall quality of man's environment is rapidly deteriorating; (4) the foregoing combination of factors makes it increasingly imperative that man manage as wisely as possible such earth resources as timber, forage, agricultural crops, livestock, soils, water and minerals, as well as atmospheric and oceanic resources; (5) in order that the wisest possible management of these resources can be achieved on a global basis, they should be inventoried accurately, quickly, uniformly, and (through a process known as "monitoring"), at suitably frequent intervals; and (6) it therefore becomes both timely and urgent to investigate the extent through the intelligent use of space-age remote sensing technology, especially that based on data acquired from the world's first Earth Resources Technology Satellite (ERTS-1).

For the first time ERTS-1 has permitted us to acquire multi-spectral data from space with very good radiometric fidelity and with resolution appropriate to a broad spectrum of natural resources applications. It has given us the capability:

1. To image and analyze vast areas of the globe in a very short period of time.

2. To obtain very broad synoptic coverage and thus to transcend boundaries of agency and ownership responsibility and even of political jurisdication.

3. To view these scenes simultaneously in four separate regions of the electromagnetic spectrum and to consider the spectral characteristics of individual 0.4 ha. units of the landscape.

4. To put earth resources and their use in a vivid, pictorial perspective provided that regional, national, or global systems of identification and annotation are developed and used.

Historically man has evaluated and planned the development, use, and management of earth resources; first from the highly restrictive view provided by ground observation, then from the substantially improved perspective of conventional aerial photography, and most recently from the still broader perspective obtainable from an earth-orbiting spacecraft. Also, historically speaking, the earth resources

themselves, have been managed quite restrictively by a multiplicity of government and private interests and, particularly, in the United States with each having its own local or small regional point of view. Consideration of resource problems in the context of small-to-major watersheds is about as close as we have traditionally come to development of a broad synoptic view of problems and their interrelationships.

In this context, it has neither been necessary to develop a unified procedure for the identification of earth resource features across broader regions, nor a truly national or global legend for their identification and annotation. Each agency, landowner, or river basin commission could achieve its stated objectives by developing its own techniques and legends, largely independent of the views and needs for coordination with others. After all, the project boundary seemingly was the true limit of concern. But when we consider the ever-increasing dependence of one region or nation on another for food, fodder, fiber and minerals and also for environmental protection, this limit of concern broadens commensurately. It is in this context that remote sensing from an earth-orbiting spacecraft such as ERTS-1 assumes its greatest potential significance. The synoptic view offered from such a platform makes it possible for a single unified legend system and identification method to be applied across all ownerships throughout a vast area and then to draw together what each responsible agency knows into a common, integrated data base--much of which can be pictorially portrayed on an ERTS image or mosaic. It becomes even more appropriate in this setting to take an ecological approach to resource inventory and environmental monitoring when relating each kind of resource area to its land use potentials and management requirements.

This new capability has made it imperative that someone investigate man's capability to make accurate, uniform, interregional interpretations of important natural vegetation, environmental, and agricultural crop features of the landscape in a way that would contribute to the solution of practical resource management problems. Consideration of this need has suggested that the concept of ecological and crop analogs might offer a working hypothesis. Consequently, we approached this investigation on the assumption that analogous vegetation types and environmental complexes should have sufficiently analogous remote sensing signatures so that hopefully they could be recognized in each of many regions from an adequate understanding of the subject/image relationships worked out in a few representative regions. Consistent with this viewpoint, we have attempted to determine some of the limits to extrapolation of subject/image relationships in the intra- and interregional context. We have been continuously alert to and curious about the global applicability of the concepts and hypothesis developed in the present studies and in much of our earlier work.

Performance of these tests imposed the secondary requirement that earth resource subjects be characterized, defined, and classified in a hierarchical mode and with sufficient consistency of criteria that both intra- and interregional analogs could, in fact, be identified through use of the same criteria. The Principal Investigator had begun development of such a classification, or legend system, with his graduate students at Oregon State University and with associates at the University of California, Berkeley, during the Apollo program

(Poulton, Schrumpf, and Garcia-Moya, 1971)[1]. This work formed the initial basis for vegetational classification into analogous units for purposes of this study. In the crops area it was initially proposed to work with both wheat and rice, the two most important world analogs of food crops. At the Sponsor's request, however, the investigation was narrowed to consider rice alone and to determine whether, within this context, parameters affecting rice yield prediction could, in fact, be detected from ERTS-1 imagery. Similarly, in the natural vegetation area our studies were limited to vegetation types of representative semi-arid regions, and to environmental factors associated therewith.

Working within these constraints it has thus been our goal to make some contributions toward a globally applicable scheme for the uniform mapping and monitoring of earth resources, environmental complexes and key food crops. Our long-term objective is to specify and test a practical procedure and system for the uniform mapping and monitoring of natural and human ecosystems so that the "World of Nations" can do a more adequate job of natural resource allocation, use and management, and also of food production and environmental protection.

---

[1] Poulton, Charles E., Barry J. Schrumpf, and Edmundo Garcia-Moya. A preliminary vegetational resource inventory and symbolic legend system for the Tucson-Wilcox-Fort Huachuca Triangle of Arizona. In Colwell, Robert N., 1971. Monitoring Earth Resources from Aircraft and Spacecraft. National Aeronautics and Space Administration, Scientific and Technical Information Office. Washington, D.C. NASA SP-275, pp. 93-115.

For operation efficiency, this investigation has been conducted under two phases: a natural vegetation and ecological analog phase, and a crop analog phase. The report is organized according to these two phases.

The specific short-term objectives were defined from the outset as set forth in the following section.

2.0 OBJECTIVES

2.1 NATURAL VEGETATION AND ECOLOGICAL ANALOG PHASE

1. Further adapt and test a uniform ecological legend for making natural vegetational resource inventories in two regions of the United States.

2. Identify the potentialities and limitations of the legend concept for the recognition and annotation of ecological analogs and environmental complexes.

3. Investigate the kinds of ecological analogs that can and cannot be interpreted from ERTS-1 imagery, and the consistency and variability in the characteristics of images of specified analogs in the conventional photographic image products.

4. Investigate the kinds of resources that can and cannot be interpreted when the ERTS-1 imagery is fortified in a multistage sampling scheme with limited amounts of aerial photography and direct ground observation.

5. Investigate specific kinds and reasonably optimum levels of ground truth required for successful application of the analog interpretation procedures.

2.2 AGRICULTURAL CROPS INVENTORY AND MONITORING PHASE

1. Determine the optimum combination of space imagery, aerial photography, ground data, human data analysis, and automatic data analysis for estimating crop yield in the rice growing areas of California and Louisiana.

2. Quantify the accuracy achievable through use of these optimum techniques of data acquisition and analysis.

3.0 SCOPE OF STUDY

This study, in its two phases, was limited to the four test areas indicated in Figure 1. These test areas are briefly described in a following section. Because of the progressively delayed launch of ERTS-A in 1972, we were provided with prelaunch aircraft simulation photography over part of our test sites. Although a good deal of preliminary examination was made of this photography, we made no serious attempt to use it because such activity would have used financial and manpower resources which we believed could be more wisely used in working with the eventual satellite imagery. Our preliminary work this this simulation photography also showed that, for the most part, it was at a scale too small to serve effectively as intermediate "ground truth" in the interpretation of the space images.

In the early months of the project, after acquisition of initial satellite data on 23 July 1972, delivery of color products and retrospectively ordered items after initial screening was so slow that project work did not move as efficiently as it should have. In addition, we had conceived the project to utilize a human image interpretation approach and to work from the standard NASA-supplied color products. To compound the delay problem, the quality of some of these products was not adequate and new imagery had to be acquired. To meet reasonable delivery schedules. a local commercial laboratory, EROS Data Center, and the USDA Western Aerial Photography Laboratory, were all drawn upon in attempts to obtain high-quality working materials, which we eventually received.

The Southern Coastal Plain (Louisiana) Test Area was not imaged

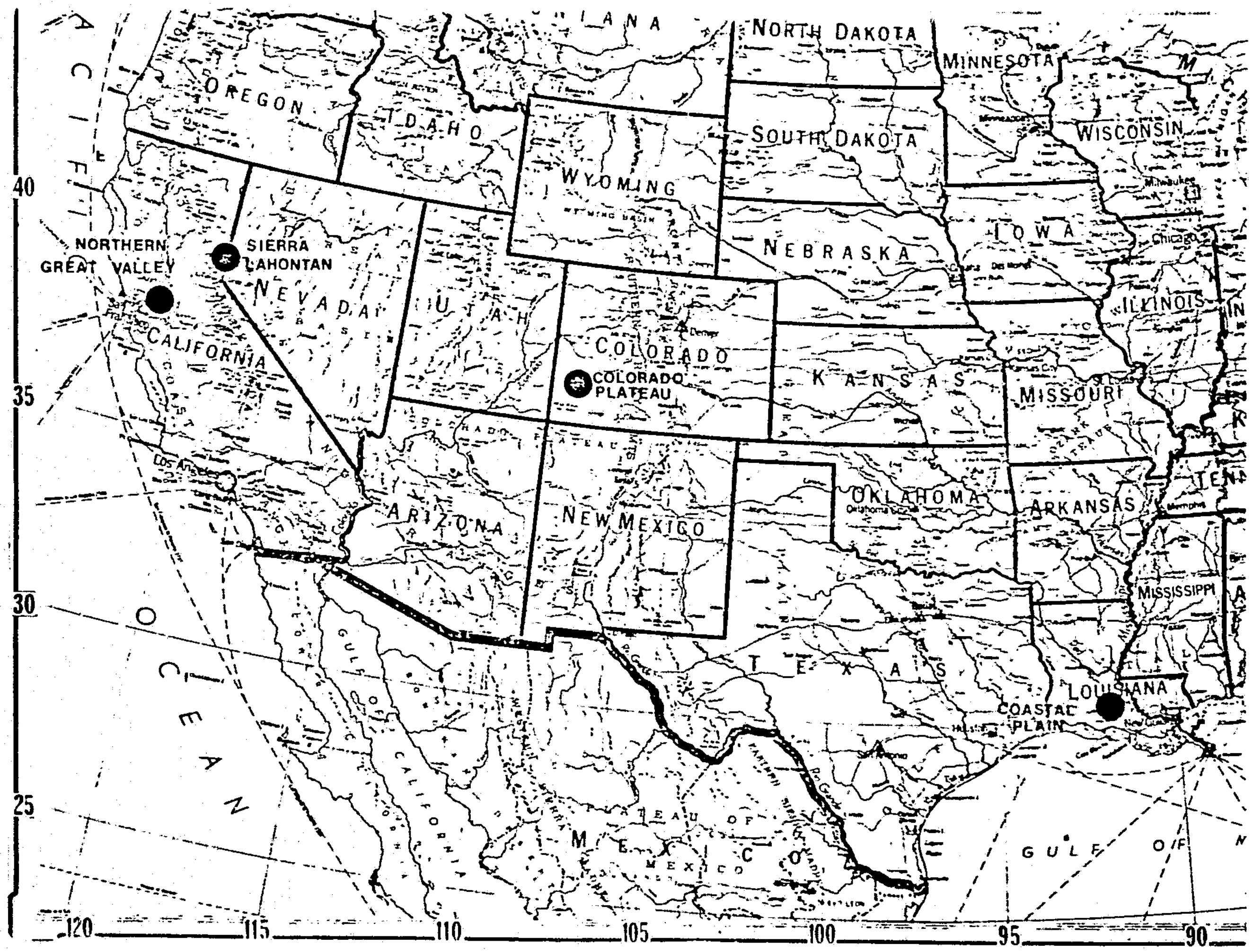

Figure 1. Location of the four interregional test areas used in this study: Sierra-Lahontan and Colorado Plateau for natural vegetation; Northern Great Valley and Louisiana Coastal Plain for rice.

successfully by either NASA support aircraft or the spacecraft to give us data for the critical seasons for rice yield prediction. However, as close to early overpass dates as possible, and consistent with support scheduling for all four test areas, we acquired low-level support photography. At these times we also obtained local farmer and experiment station cooperation and acquired a large amount of ground data with the expectation that the combination of RB-57-F support photography, our own, and the satellite data, would be adequate for this phase of our study. With this investment and in the absence of high-flight aircraft photography as well, we were extremely disappointed when we found it necessary to drop the Louisiana test site from further consideration, primarily because of the subsequent lack of suitably cloud-free ERTS-1 imagery of this area.

In the Northern Great Valley Test Area (California), we obtained aircraft imagery and all the supporting ground data. Essentially all of the planned dates of satellite imagery were sufficiently cloud free to be useful. Supporting high-flight coverage was also very good for this test area.

Adequate satellite imagery of very high quality was obtained over both of the ecological analog test sites (Sierra-Lahontan, California-Nevada; and Colorado Plateau, Grand Junction to Four Corners). We obtained low-level aircraft support imagery and ground truth data of these test sites as planned, but in some cases the NASA support aircraft coverage fell short of plan because of weather and cloud problems, flight line location errors, and certain compromises that were required to service other contracts.

These collective problems had a strong financial impact on the project in relation to objective attainment. We requested overrun funds from NASA in December, 1973, deactivated the ecological analog phase of the investigation, and strongly curtailed work on the crops analog phase on 18 February 1974. On 29 August 1974 we were awarded enough additional funds to prepare a final report, essentially on the work performed in early 1974. We were not able to run all of the tests in our approved plan of work or to fully achieve all objectives. We were able, however, to contribute significantly to most of the objectives, and thus to show that the working hypothesis is sound, the legend system is highly workable and effective for interpretation of ERTS imagery, and the analog concept is sound as a basis for inter-regional image interpretation. In the following pages we will report on those features of the original work plan that available funding permitted.

3.1 TEST AREA DESCRIPTIONS

3.1.1 THE COLORADO PLATEAU TEST AREA

This test area includes vegetation zonation patterns highly similar to the Sierra-Lahontan with many vegetation analogs as well as a few vegetation types unique to its surrounding region (Figure 2). The zonation pattern within the Colorado Plateau Test Area is from the salt desert (*Atriplex* dominant) zone, through the sagebrush or shrub steppe, pinyon-juniper, oakbrush, ponderosa pine, to aspen and spruce-fir, with some essentially alpine vegetation associated with the high mountain rocklands above timberline. A mixed coniferous type (Douglas-fir, true

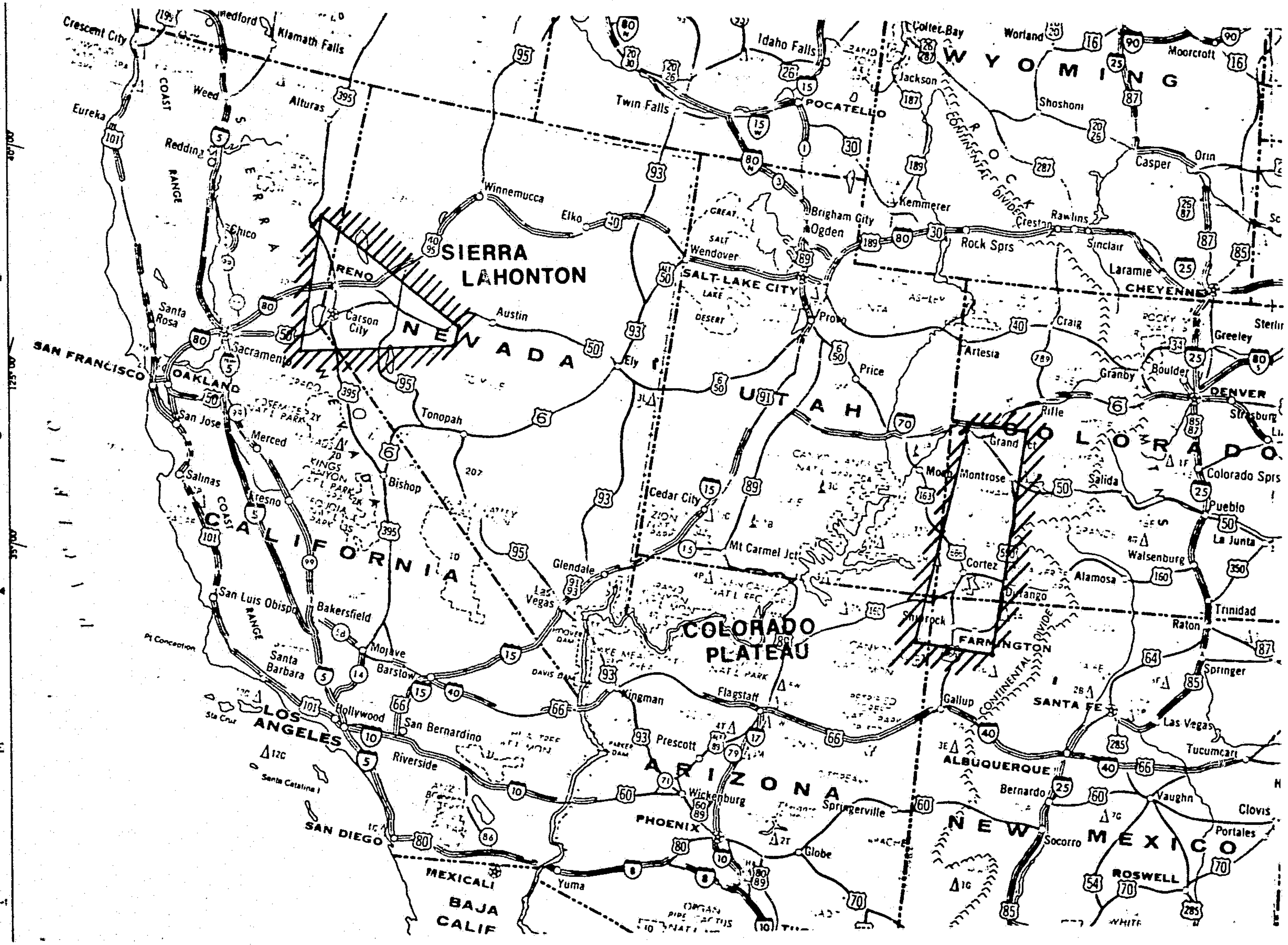

Figure 2. Approximate boundaries of the two natural vegetation test areas.

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fir, and ponderosa pine) occurs in the area, but it is generally restricted to northerly aspects in the intermediate and upper elevations of the ponderosa pine zone. The spruce-fir zone is well-defined immediately below timberline. The two regions are constrasted particularly in the high preponderance of the deciduous Gambel oakbrush type of the Colorado Plateau with very limited distribution of sclerophyllous shrub types, such as manzanita (Arctostaphylos spp.). The area has important geologic and mineral significance but in these respects is strongly contrasted to the Sierra-Lahontan. There are rather extensive areas of irrigated agriculture heavily oriented to livestock ranching. Forestry, mining, recreation, and wildlife are important in the region. This test area includes parts of two Indian reservations and large amounts of Bureau of Land Management and Federal Forest Service land.

3.1.2 THE SIERRA-LAHONTAN TEST AREA

Direct analogs with the Colorado Plateau Test Area occur here (Figure 2). They are found in the salt desert zone, the sagebrush or shrub zone, the pinyon-juniper zone, and also in the Jeffrey pine zone, which is analogous with the ponderosa pine zone of the Colorado Plateau. In the Sierra-Lahontan Test Area, the spruce-fir zone is not distinctive as in southwestern Colorado. The spruce-fir of the latter test area is ecologically but not floristically analogous to the mountain hemlock types below timberline in the Sierra-Lahontan Test Area. One might expect the signatures of these two types, however, to be similar. In the latter area, the sclerophyllous shrub type predominates in most of the forest openings, and Gambel oakbrush is entirely absent. Deciduous oak trees are, however, present in the Jeffrey pine zone. This is in floristic contrast with the

common occurrence of Gambel oak in the understory of ponderosa pine forests in the Colorado Plateau Test Area. In spite of the floristic contrast, these two types are ecologically analogous and one might expect their signatures to be similar in the two regions. The mixed conifer type (more extensive in this region) is essentially analogous with the north-aspect, mixed conifer types of the Colorado Plateau. There is an Indian reservation in the Sierra-Lahontan Test Area with similar preponderance of other federal land. The patterns of agriculture and crop types are highly similar with livestock production being a significant part of the local economy. Wildlife and recreation are also very important in this region. Aspen types occur but are much more restricted than in Colorado. The two regions are strongly contrasting geologically but, in spite of this, good vegetational analogs do occur.

3.1.3 THE COASTAL PLAIN TEST AREA

If adequate ERTS-1 imagery had been obtained, this test area, located near Crowley, Louisiana, would have been an excellent study area for the rice crop analog comparison and yield determination because the potential is high both for excellent yields to be obtained and also for severe problems to arise due to disease and pest attacks and frequent adverse weather. This test site is described in greater detail in a subsequent section.

3.1.4 THE NORTHERN GREAT VALLEY TEST AREA

This test area is located in part of the Sacramento Valley of northern California where rice is one of the major crops of the region. This test site also is described in greater detail in a subsequent section.

4.0 QUICK-LOOK ASSESSMENT

Our quick-look evaluation procedures are included in the final report because it is felt that they may be useful to others in screening imagery for specific projects. We found it very useful to indicate each scene area by a local geographic name taken from a prominent feature close enough to the frame center to appear in all images of the scene location. These frame names then became permanent identifiers of the scenes, were entered on each copy, and provided an effective way to communicate about the file.

Obviously, initial screening would be based on the appropriateness of the season or date of imagery and then on cloud cover and grossly apparent quality of the image as judged from black-and-white photo products from Band 5, 7, or both. Initial images were screened and reported according to the key word list as required by NASA, but we did not consider this adequate documentation of the information content and interpretability of the images. We developed a supplemental form (Figure 3) which, though not perfect, is better as a record of the potential usability of individual scenes. We made all of our quick-look evaluations from 9x9-inch black-and-white prints or transparencies of Band 5; but, after having had the experience, we would recommend that critical quick-look screening be done on a color additive viewer whenever the required 70mm positives are available. Candidate images for a specified application can be more effectively screened in a color additive viewer. While for many purposes one may not need to fill out a form to decide on image usability, the procedure does force one to study the image more intently, and it provides a permanent record for future references in the absence

QUICK LOOK

PHOTO QUALITY AND INTERPRETABILITY SUMMARY

Type of Imagery: (X) ERTS 1; ( )U-2/RB-57; ( ) Aircraft. Photo Date: 9/16/72

Area or Location: Sierra-Lahontan. Band/Film-Filter: MSS-5

Frame No(s).: 1055-18053; Frame Name: Walker Lake

Type Imagery: MSS-5 B&W Print; Matte finish. Scale: 1:1,000,000

Site Condition: ( ) Wet; (X) Dry. Image Useful in Project? (X) Yes; ( ) No.

FEATURES IMAGED	Percent Frame	Interpretability
100 - Barren land	2	A
110 - Playas	2	A
120 - Aeolian Barrens		
130 - Rocklands		
200 - Water Resources	2	A
210 - Ponds, Lakes, Reservoirs	2	A
220 - Water Courses, Permanent	1	B
280 - Snow/Ice	1	A
300 - Natural Vegetation		
301 - Density & Vigor High	2	B
302 - " " " Moderate	4	B/C
303 - " " " Low		
304 - Vegetation Dormant	5	B/C
310 - Herbaceous Types		
320 - Shrub-Scrub Types	4	A
324 - Microphyllous Salt-Tolerant	3	B/C
325 - Shrub Steppe (Sagebrush)	3	B/C
326 - Evergreen Macrophyllous		
327 - Deciduous Macrophyllous		
330 - Savanna Types	+	D
340 - Forest and Woodland Types		
341 - Needleleaf	4	C
342 - Broadleaf Deciduous	1	D
343 - Broadleaf Evergreen		
344 - Needleleaf-Broadleaf		
400 - Agricultural Crop Land	2	A
410 - Cover Crops, Field & Seed	2	A/B
411 - Cereal and Grain Crops		
411.6 - Rice		
500 - Urban/Industrial Lands	1	C/D
540 - Transportation Facilities	1	B
580 - Resource Extraction (Mining)	1	C/D
600 - Obscured Earth Resources	0	
610 - Clouds (Type: ______)		
620 - Dust		
630 - Smoke		
640 - Smog		

Use Percent Classes

1 =	+ - 1%
2 =	1+ - 5%
3 =	5+ - 25%
4 =	25+ - 50%
5 =	50+ - 75%
6 =	75+ - 95%
7 =	95+ - 100%

Interpretability Classes

A = Positive, little chance for error.
B = Reasonable Certainty, Errors inconsequential.
C = Modest Chance for Error Highly dependent on associated/convergent evidence or local familiarity with area.
D = Large Chance for Error, little better than a guess.

Interpreter: CEP

Date: 9 Dec 72 (day,month,year)

NOTE: Rate legend items only once for each scene unless image changes occur or quality improves. Generally score only RBV-2 or MSS-5.

Change Evident Since Last Examination, (X)Yes; ( )No; ( )Not Applicable. If YES, Explain

Snow on Mt. Patterson 11,712'

REMARKS: All Fallon-Eastgate strip on No. edge of frame. Good hiflite support. Order color print.

Continued on Back ( ).

Figure 3. A useful quick-look evaluation form for preliminary screening of ERTS imagery.

of a complete file of the color products. We have been surprised at the cross discipline and interproject use made of many of the images EarthSat has acquired on various projects. Careful completion of a form such as this has the following advantages:

1. It organizes the approach to initial evaluation and gives a good idea about the information content of each frame, quality of imagery, and interpretability of the classes evident.

2. As these records accumulate, comparison of them soon reveals the frames that will be most useful for the objectives of a given project.

3. If entries can be made by a multidiscipline team of examiners, they have significant training value as the team members learn from one another by pooling their initial judgment and discussing problems of interpretability.

4. On occasion, others will want to know about the coverage in a specified area. This record is an excellent way to communicate information, especially if all members of a multidiscipline team pool their judgment in the quick-look evaluation.

5.0 COLOR RECONSTITUTIONS

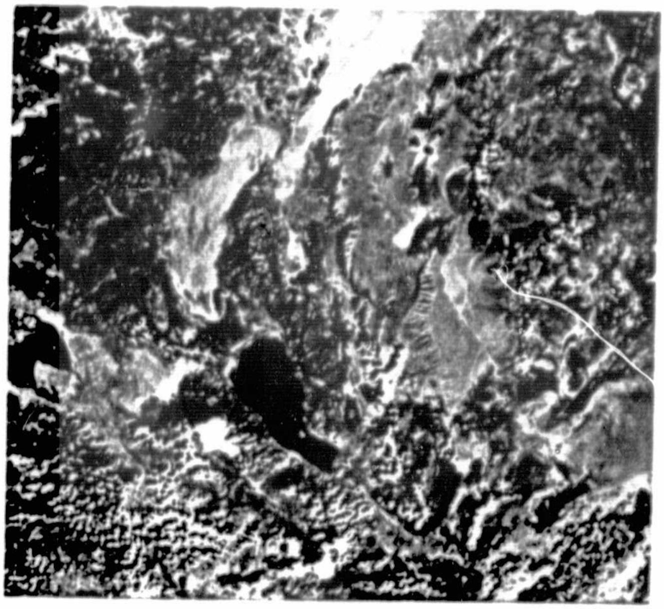
While we used the color additive viewer for some quick-look work, practically all of our serious interpretation was done with Band 4, 5, and 7 data reconstituted by the photographic color separation technique. Early in the project we made and compared some experimental color additive products with Bands 4, 5, and 6 versus 4, 5, and 7, copied on Kodacolor film with and without an 80A color correction filter. In general, from this early experimental work we found the 4-5-6 products with the 80A color correction filter to give the most interpretable contrasts among the earth resources features of interest to our project. We subsequently standardized 4, 5, and 7 because of common practice. We also experimented with optimum dial settings (Lamp intensities) for our particular color additive viewer (Addcol by International Imaging Systems, Inc. (I^2S)). These experiments, with the color recombination of 32 scenes in both the Sierra-Lahontan and the Colorado Plateau Test Areas, suggested the following optimum settings of illumination levels when copying on tungsten corrected, EHB-120 film at a reduction of 0.51X exposed for four seconds. This procedure seemed on the average to give maximum differentiation of earth surface features.

Band No.	Filter	Illumination Dial Setting
4	Blue	7.0
5	Green	7.5
7	Red	7.5

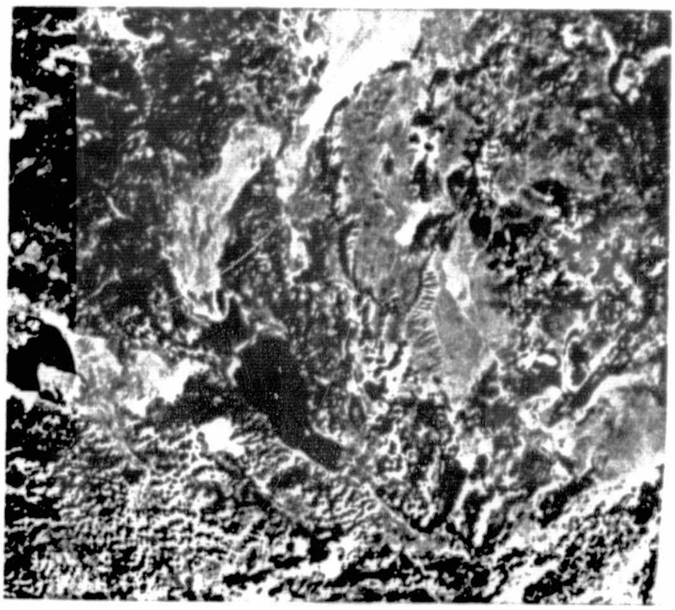
We did some comparative evaluation between Band 4, 5, and 7 versus only 5 and 7 reconstitutions. Because only two bands have to be registered, and atmospheric haze affects Band 4 the most, the latter combination has the advantage of frequently showing sharper detail and more

linear features or textures and patterns attributable to relief--all of which is important in vegetational and soils interpretations. Where one becomes accustomed to interpreting the more conventional Band 4-5-7 product, on the other hand, certain areas show a misleading pink hue that is not necessarily associated with as lush vegetation as would be expected from 4-5-7 interpretive experience.

We made some comparisons of the 4-5-7 versus 5-7 color product for vegetational differentiation in the pinyon-juniper woodland, sagebrush, and saltbush zones of both test areas. While the 5-7 product is useable, it discriminates fewer vegetation types and usually gives a misleading pink hue to sagebrush zone vegetation (Figure 4). The browns and reddish browns tend to be entirely lost in this product. This preliminary experimentation can be summed up essentially as follows: If interregional analog signatures are to be correctly identified, compared, and documented, utmost care and highly professional state-of-the-art laboratory technique must prevail. All products to be used should be produced at the same time to minimize the usual problems associated with precision color photographic products. In addition, a carefully standardized product should be prepared as a reference for color balance and saturation in the event of additional orders from the photo laboratory, and the laboratory should keep careful and complete records of all processing details with the hope that residual variation will be essentially held to batch number in the film or photographic paper used.



Bands 4, 5, 7



Bands 5, 7

Figure 4. A comparison of the 4-5-7 and 5-7 color reconstitutions for interpretation of vegetational analogs. Note the more extensive pink hue in the 5-7 reconstitution and the general absence of some of the brownish hues which increase interpretability of the 4-5-7 product. We have a strong preference for the standard 4-5-7 color product in a broad spectrum of vegetation interpretation work.

6.0 GROUND TRUTH PROCEDURES

Since one of the purposes of our investigation was to determine at what level of classification one could delineate and identify natural vegetation analogs from ERTS-1 imagery, it was essential to obtain data at specified locations that enable identification of the natural vegetation at four or five hierarchical levels. It was not sufficient for purposes of our study to merely identify conifer forests, hardwoods, brushfields, and grasslands as many investigators have been doing since the days of Apollo experiments. We hoped, for example, to determine how far one could go to differentiate kinds of conifer or hardwood forests, kinds of shrublands, and kinds of grasslands. This required that our ground truth methods identify plant community types within each of these classes. We accomplished this task by documenting, at each ground observation and low-level overflight point, the prominent species that made up each plant community type that was large enough to be imaged on ERTS-1. We then classified each example into its various, higher hierarchical levels. In most cases, our ground truth records were at the fourth or fifth level of classification.

We used four main sources to accumulate a ground truth bank:

1. Existing agency maps of natural resources within each of the major test areas,
2. Our own low-level, aerial overflight with tape-recorded notes and aerial photography--both vertical and oblique,
3. NASA-provided high-flight photography, and

4. Direct ground observation on easily traversed transects selected to be as representative as feasible of the ecological variability and dominant conditions within the areas overflown.

An accurate location map was kept of all observations, whether from the air or ground. The NASA overflights were plotted on a Band 5 ERTS mosaic of each test area. Our own overflights and photo missions were plotted on 1:1,000,000 aeronautical charts to show not only the flight path but also the location and direction of key photos and recorded notes. All ground mission observations and major transects of aerial photography were plotted on 1:250,000 scale USGS topographic sheets. Locations were keyed by number to the photographs and ground truth records (Figure 5).

The foregoing are standard ground truth methods of the type that have been used by EarthSat personnel in similar kinds of projects for years. The work could have been done more efficiently had we had 1:250,000 scale ERTS enlargements with matching transparent mylar overlays of the road and urban infrastructure so that specific image areas could have been directly identified from the air. These enlargements would have been of little value for the ground reconnaissance because of the difficulty of positive location. The "ant's eye view" from the ground is too restrictive to match the landscape with the perspective of the ERTS image. A color reconstituted satellite image and a helicopter or fixed-wing aircraft for transportation are essential to efficient ground truth work and interpretation checking of ERTS imagery.

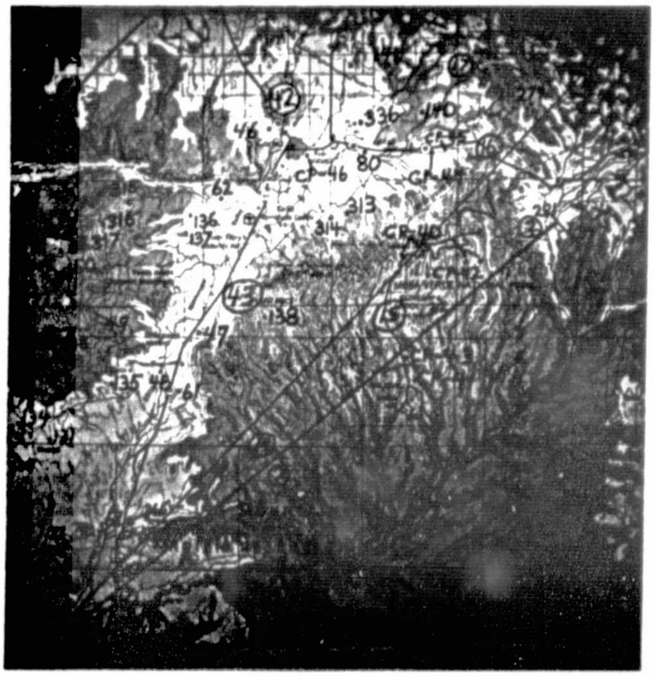


Figure 5. All ground truth observations were located as they were acquired on 1:250,000 scale topographic maps. Support aerial photography missions were also charted on the same maps as indicated by the SW-NE trending black line in this illustration. Locations of key examples of each analog were then transferred to 1:250,000 scale ERTS color enlargements for use in interpretation testing experiments. Maps such as these are essential to the accessing of the ground truth record once it has been obtained and filed. The ideal way to match ground truth with the ERTS enlargement is by use of a mylar print of the 1:250,000 planimetric and topographic detail.

7.0 THE LEGEND SYSTEM

A classification of subjects of interest is an essential first step toward the identification of any earth resource features detectable and delineated or mapped by remote sensing. This process of classification may be looked upon as legend development. Legends are the shorthand by which identifiable features are labeled and characterized. They normally consist of three components: a symbolic legend or brief numeric or alphanumeric system for identification of each class, a technical legend or brief word description or name of the class, and a descriptive and interpretive legend which summarizes the criteria for classification and, to the extent knowledge permits, the characteristics and features of the class that are salient to practical application and management. A completely operational legend also includes an interpretive narrative or table that relates each class to practical resource use and management alternatives. It is the descriptive and interpretive legend that gives the classification substance in terms of decision making and problem solving. Since this project was concerned primarily with the testing of procedural concepts and methods, no attempt has been made to complete the descriptive and interpretive legends for all classes.

The legend system used in this investigation was first conceived and carried through preliminary developmental phases by the Principal Investigator, his graduate students, and research associates in connection with

the Apollo program. More specifically, the S065 experiment aboard Apollo IX. (Poulton, Schrumpf, and Garcia-Moya, 1971.) In the interim period the legend has undergone many iterations and carefully thought-out revisions. It had become reasonably stabilized and rather thoroughly tested by 1972. Since the concepts, philosophy, classification criteria, and an updated version of the legend format were subsequently published by the Principal Investigator (Poulton, 1972),[1] it is not considered necessary to repeat the material in this report. However, an abstracted version of the legend as it applied to this project is included as Appendix A. The specific legend classes used in this investigation are included in the following section on the natural vegetation analogs found in both regions.

In addition to annotation of interpreted images and maps, the legend system is particularly useful as a "shorthand" to record vegetational observations, particularly in low-level air checking. It is also appropriate for quickly documenting ground observations where additional sets of detailed vegetational and site data are not required.

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[1] Poulton, Charles E. 1972. A comprehensive remote sensing legend system for the ecological characterization and annotation of natural and altered landscapes. Technical Paper No. 3435, Oregon Agricultural Experiment Station, Corvallis, Oregon. Proceedings Eighth International Symposium on Remote Sensing of Environment. 2-6 October 1972. Willow Run Laboratories, ERI, Environmental Research Institute of Michigan, Ann Arbor, Michigan, pp. 393-408.

8.0 VEGETATION ANALOGS

Vegetation analogs may be defined at a number of levels in a hierarchical classification from the very broadest (physiognomic) types down to highly specific plant community types. These latter consist of reasonably constant assemblages of species that grow compatibly together on homogeneous parts of the landscape, on similar sites. Criteria for recognition of the very broadest types are physiognomy or gross appearance and similarity of growth form; e.g., forests, grasslands, and shrublands. The next level of refinement brings structure or vertical layering of growth form types, periodicity of leafing out, and/or leaf types into consideration. These criteria define such subclasses as shrub steppes with a substantial herbaceous understory versus desert shrub/scrub with a depauperate herbaceous understory; open forest types with a shrub understory versus forest types with a grass or herbaceous understory; conifer versus hardwood; or evergreen versus deciduous forest and shrub types. In each of these classes regional and global analogs do occur and can be rather easily recognized. Such considerations as these are the basis upon which most of the maps and classifications of world geography have been produced.

Below these broadest levels one can bring in gross taxonomic similarities among the dominant species--or particularly genera--as a criterion of classification; for example, ponderosa pine forests, sagebrush steppes, and creosote bush deserts. To the degree that the same or ecologically equivalent plant taxa occur interregionally, and in many cases intercontinentally, regional or global analogs can be recognized and described. At the next level of refinement one is concerned primarily with

specific assemblages of plant species in the community or plant sociological context. At this refined level analogs tend to be identifiable only in the intraregional or ecological province context. The region or province is defined by the similarity of overlapping distributions of the character species which define the analogous units and by a specified degree of commonality in the environment of the region.

An outstanding North American example of widespread analogous vegetations at the stand dominant (quaternary) level is seen as one compares the ponderosa pine/blue-bunch wheatgrass vegetation of the Northwest with the ponderosa pine/Arizona fescue vegetation of the southern Rocky Mountains, and with the longleaf pine/wiregrass communities of the Southern Coastal Plain which also possess many physiognomic and structural similarities to the other two.

All of the ground truth records for the two test areas were critically compared and a set of mappable vegetation and environmental analogs were identified both intra- and interregionally. These were classified and assigned symbols according to the unified legend (Table 1). Selected sets from among the list were located on ERTS imagery as ground truth in mapping experiments and for possible use in quantitative interregional tests of analog interpretability. Unfortunately, we had to terminate work on the project for lack of funds, having made only intraregional tests on ERTS black-and-white Bands 5, 7 and 4, 5, 7 color reconstitutions.

Table 1. Analogs Represented in Test Areas
(+ = well represented with useable examples;
x = poorly represented, marginally useful examples)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
100-700	All primary classes	+	+
100	Barren Land	+	+
110	Playas	+	x
120	Aeolian barrens	x	+
130	Rocklands	+	+
150	Badlands	x	x
160	Slicks	+	
180	Man-made barrens	x	x
200	Water Resources	+	+
210	Ponds, lakes, and reservoirs	+	+
220	Water courses	x	x
280	Snow/Ice	+	+
300	Natural Vegetation	+	+
310	Herbaceous types	+	+
312	Annual types (mostly *Bromus tectorum* L.)	+	+
313	Forb types (Broad-leaved, herbs dominant)	x	x
314	Steppe, grassland, and prairie	+	x
315	Meadows	+	+
315.1	Sedge and sedge-grass meadows	+	+
320	Shrub/scrub types	+	+
324	Halophytic shrub types	+	+

Table 1 (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
324.1	Greasewood types (*Sarcobatus vermiculatus* (Hook.) Torr.)	+	+
324.2	Saltbush types (*A. nuttallii* Wats., *A. confertifolia* (Torr. and Frem.) Wats., *A. obovata* Mog.)	x	+
324.3	Shadscale/Budsage types (*Atriplex confertifolia*-*Artemisia spinescens* Eat.)	+	+
324.4	Bailey's greasewood (*S. baileyi* Cov.)	+	
324.5	Blackbrush types (*Coleogyne ramosissima* Torr.)		+
325	Shrub steppe types	+	+
325.1	Sagebrush types (*Artemisia* spp.)	+	+
325.2	Sagebrush-Bitterbrush types (*A. tridentata* Nutt.-*Purshia tridentata* (Pursh) D.C.)	+	x
325.3	Bitterbrush types	x	x
326	Sclerophyllous shrub	+	x
326.1	Manzanita chaparral (Arctostaphylos spp.)	+	x
326.2	Oakbrush chaparral (Sclerophyllous-Evergreen *Quercus* spp.)	+	
326.3	Snowbrush (*Ceanothus velutinus* Dougl.)	+	+
326.4	Chamise (*Adenostema fasciculata* H. & A.)	+	
326.5	Curlleaf Mountain Mahogany (*Cercocarpus ledifolius* Nutt.)	x	x
327	Macrophyllous shrub	+	+
327.1	Oakbrush chaparral (*Q. gambelii* Nutt.)	+	
327.2	Mountain brush, Serviceberry-Snowberry-Birch leaf Mountain Mahogany (*Amelanchier* spp.-*Symphoricarpos* spp.-*Ceanothus montanus*)	+	+

Table 1 (cont'd.)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
327.3	Willow (*Salix* spp.)	+	+
330	Savanna-like Types	+	+
336.1	Pinyon (*Pinus* spp.)-Juniper (*Juniperus* ssp.)-Shrub Savanna	+	+
340	Forest and Woodland Types		
341	Conifer forests	+	+
341.1	Juniper or Pinyon-Juniper (*Pinus monophylla* Torr. and Frem. or *P. edulis* Engelm., *Juniperus osteosperma* (Torr.) Little)	+	+
341.2	Ponderosa or Jeffrey pine forests (*Pinus ponderosa* Dougl., *P. jeffreyi* Grev. and Balf.)	+	+
341.3	Mixed conifer forests (Pine-Douglas-fir-true fir-Hemlock) (Pinus-Pseudotsuga-Abies-Tsuga)	+	+
341.4	Spruce-fir forests (*Picea engelmannii* Parry ex Engelm, Abies lasiocarpa)	+	+
341.5	Lodgepole pine forests (*Pinus contorta* Dougl.)	+	+
342	Broadleaf forests	+	+
342.1	Deciduous oak woodlands (*Quercus kelloggii* Hewb.)	+	x
342.2	Evergreen oak woodlands	+	-
342.3	Bottomland cottonwood (*Populus wizlizenii* (Wats.) Sarg.)	+	+
342.4	Aspen types (*Populus tremuloides* Michx.)	+ x	+
343	Conifer-hardwood forests	+	+
343.1	Aspen-spruce-fir forests	-	+

Table 1 (Concluded)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
343.2	Pine-oak forests	+	-
414.0	Cleared juniper rangeland, seeded to grass	+	+
425.1	Cleared juniper rangeland, sagebrush understory	+	+
500	Agricultural cropland	+	+
600	Urban and industrial lands	+	+
700	Extractive industry	x	x

9.0 INTRAREGIONAL ANALOG INTERPRETABILITY TEST[1]

An experiment was conducted using 40 student photo interpreters and three experienced interpreters to determine the intraregional interpretability of selected images. For this experiment a portion of the Colorado Plateau Test Area was selected.

The training and test images were located in an area that includes an almost ideal transect of natural vegetation from sagebrush steppe through spruce-fir and alpine forest conditions. The approximate center of the experimental area is located at latitude 38°00' north and longitude 108°20' west. The approximate dimensions of the area are 20 by 60 nautical miles. It extends from the vicinity of Montrose, Colorado, across the Uncompahgre Plateau, the San Miguel River, Disappointment and Dry Creek Valleys to the Dolores River near Cortez, Colorado. The elevations range from high valleys at about 5,900 to 7,000 feet, to mountain ridges and peaks between 9,500 and 10,000 feet.

The vegetational transect includes an excellent representation of analogs widely represented in western North America. The vegetational zones and major types represented are sagebrush, pinyon-juniper, Rocky Mt. oakbrush, ponderosa pine, and spruce-fir, with extensive stands of aspen and many mountain meadows interspersed through the spruce-fir zone. All training and test locations were positively identified from ground,

[1] This section of the report involves a partial amplification of comparative interpretation work done on another NASA-funded project (Contract No. G-089). Special attention was given to relevance of the work to objectives of this project. It is included here and in the Crops Analog section because funds under this project were not adequate for completion of interpretation tests.

low elevation aerial reconnaissance or support aerial photography. Photo examples of these types appear in Figures 6 through 16. In general, the pinyon-juniper zone begins at about 5,900 to 6,000 feet elevation and the commerical forest types at about 7,000 to 8,000 feet. Spruce-fir and aspen are common in the 9,000 to 10,000 foot elevations, and timberline generally is well above 10,000 feet.

Landforms are particularly evident on the imagery of this experimental area and, for the experienced interpreter, the landform/vegetation relationships are a particular aid to interpretation.

9.1 COLORADO PLATEAU INTERPRETATION TEST

Using multiband images from one scene of ERTS-1 imagery, photo interpretability tests were conducted using 40 photo interpreters. The ERTS studies were part of an ERTS/EREP comparison. The majority of interpreters were relatively inexperienced university students who were currently taking courses in photo interpretation. The tests were rigorously controlled by supervision and a set of instructions designed to maintain consistency. Each interpreter identified a prescribed set of 60 images after having critically examined and studied a training set covering the same subjects. In addition, experienced staff interpreters took the test and made other subjective evaluations. The ERTS frame used, number 1389-17195, was acquired on 16 August 1973 over our Colorado Plateau Test Area. Interpretation was done from a standard infrared color composite and from Bands 5 and 7 in black-and-white. Obviously, the most crucial problem in testing was in producing uniform and consistent color saturation and balance among the prints used.

Figure 6. Legend Unit 324.3. This is the vegetation type at lowest elevation in the test area. It is salt desert or shadescale (Atriplex confertifolia) dominant. This scene is typical of the stature and sparse vegetation cover in this zone where the image is more strongly influenced by surface soil conditions. Variations in stoniness, surface roughness, and parent material often suggest finer delineations that are not vegetation related at quaternary level.

Figure 7. Legend Unit 325.1. This is a view of the sagebrush (Artemisia tridentata) vegetation type, which typically lies between the salt desert and the pinyon-juniper types, extending into the latter zone as an understory but occurring also as pure types or inclusions of sagebrush throughout the pinyon-juniper zone and into the ponderosa pine zone. This image of this analog may or may not be strongly influenced by soil surface conditions. In spring it tends to have a light pink cast if understory grass cover is good; if not, soil predominates and the image is more like 324.3 except that the taller, denser sagebrush tends to give it a slightly denser more blue-grey image.

Figure 8. Legend Unit 341.1 This area supports a typical stand of pinyon-juniper (Juniperus osteosperma-Pinus edulis). In some areas this type includes a broadleafed deciduous shrub associate, oakbrush (Quercus gambelii). In some cases, oakbrush will form pure stands within the pinyon-juniper zone where moisture levels are more favorable to give a brighter pink mottling to the image. These tree stands may open up to a savanna-like type (336.1) in which case they are nearly impossible to separate from the 320 type that characterizes the understory.

Figure 9. Legend Unit 341.2. This is a view of a typical stand of ponderosa pine (Pinus ponderosa). The understory cover in this community may vary from pure bunchgrass or sagebrush-grass mixture on drier sites to an oakbrush understory on moist sites. The predominant undergrowth shrubs in this scene are oakbrush. In some cases the image of this type is difficult to separate from 341.1 except on the basis of relative elevation.

Figure 10. Legend Unit 341.4. This is a typical ground view of the highest elevation forest type in the test region, spruce-fir (Picea engelmannii-Abies lasiocarpa). This forest type extends to timberline in the high mountains. Small lakes, ponds, and meadows are quite common, as the foreground suggests. These usually cause strongly contrasting variations in the image area. This analog has a particularly unique dark brown signature.

Figure 11. Legend Unit 342.4. This photo shows a typical stand of aspen (Populus tremuloides). This deciduous woodland is found in the spruce-fir zone where it becomes the predominant tree species after severe burns. It is, therefore, found in all degrees of mixture with spruce and fir as natural succession returns to the latter coniferous forest types. Summer and late fall imagery is useful in separating aspen from oakbrush, 327.1, when elevation, slope position, aspect and intermixture with 341.4 do not give the clues to correct identification.

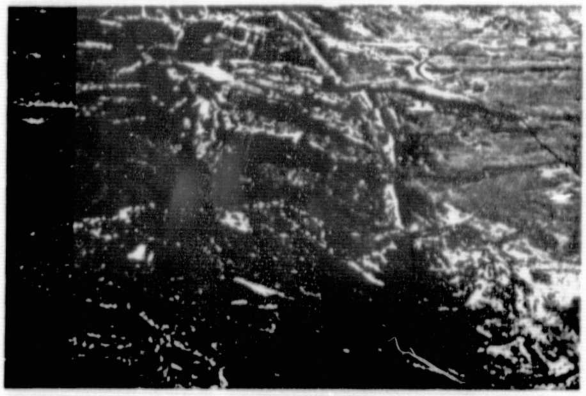

Figure 12. This scene shows a representatively sharp ecotone between the brownish saltdesert vegetation, 324, on the right and the typical pinyon-juniper, 341.1, vegetation on the left. In these arid and semi-arid regions, vegetation commonly changes with landform and geologic types, as in this example.

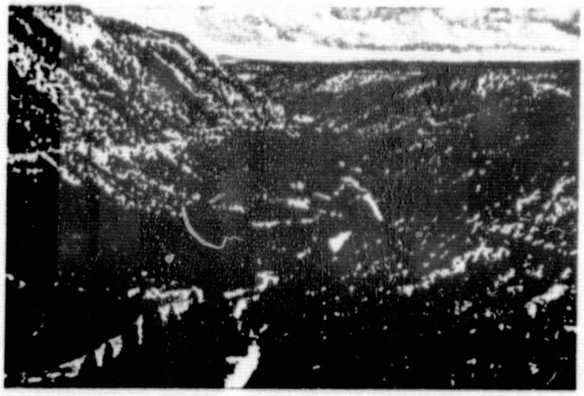

Figure 13. This scene illustrates the normal variability in density of the pinyon-juniper type, 341.1, as influenced by aspect and soil conditions. The valley slopes are covered by the pinyon-juniper type and the tall trees on the plateau in the right background are ponderosa pine, 341.2. Note also the typical extension of spruce, 341.4, oakbrush, and other mountain shrub types, 327, down the valley bottom.

Figure 14. This scene is typical of the spruce-fir type, 341.4, as it approaches timber-line where barren rock, 430, and true alpine vegetation determine image characteristics. Note especially the meadow type, 315, and lake, 210, in the foreground. Ecotones between forest and meadow generally tend to be abrupt, as in this scene.

Figure 15. Important vegetation changes occur within highly similar landforms at higher elevations under subhumid conditions. However, these changes usually occur in response to more subtle soil differences. For example, the foreground of this view consists of oakbrush, 327.1. A stand of aspen, 342.4, occurs in the mid-ground on the right, and the coniferous forest type in the background is ponderosa pine, 341.2. Note the difficulty one would anticipate in accurately mapping this vegetation mosaic at exceedingly small scales. The most feasible separation would be merely between (a) the oakbrush, with its inclusions of aspen and grassland, and (b) the ponderosa pine type, ignoring the inclusions.

Figure 16. This scene provides a perspective of the high elevation zonational pattern. This photograph was taken in May as the first clones of aspen were beginning to leaf out at the lower elevations (note the green patch of aspen, 343.1, in the foreground). The extensive surrounding type is oakbrush, 327.1, in the deciduous stage. The gray areas in the foreground and the grayish belt just below the snow and conifer line in the background are stands of leafless aspen, 342.4. The darker toned areas around the lake are ponderosa pine, 341.2, and the near-black areas interspersed with the snow fields, 280, are spruce-fir, 341.4.

The vegetation analogs used in the test were pinyon-juniper woodland, ponderosa pine forest, wet sedge meadow type, aspen forest, spruce-fir forest, and an undifferentiated "other vegetation types" category.

The data for all 40 interpreters are summarized in the commission-omission error tables that follow (Tables 2, 3, and 4). These tables shed some light on the nature of errors and where the problems lie in both training and recognition capability. Critical study of these kinds of tables enables one to postulate some of the reasons for interpretation errors. This knowledge, played back through the training program, can help build competence.

Out of 2,400 interpretation decisions on each film type, the total percentages correct are: ERTS color, 71; ERTS Band 7, 62; and ERTS Band 5, 46 percent. This strongly supports the exclusive use of color reconstitutions for vegetational interpretation, although Band 7 may be suitable when one considers its superiority for imaging free water surfaces that exceed the nominal resolution limits of the system. This is consistent with the conclusions from the statistical tests reported below.

Consideration, for example, of the commission errors for juniper, "J", gives a clue as to why some of the interpretation errors are made. In color, juniper is most commonly misinterpreted as pine, "P", mountain meadows, "W", and other, "X" (Table 2). Dense stands of juniper have much the same brownish color (in CIR) as dense stands of ponderosa pine (the "P" subject in this case), especially where the juniper is not associated with Gambel's oak. Where juniper is associated with Gambel's oak, it would generally be in a somewhat linear feature along localized areas of higher soil moisture within the juniper stand. These features would both

Table 2. Commission-Omission Errors[1] and Accuracy of Interpretation from ERTS Color Infrared Reconstituted Images

PI Calls	Ground Truth: J	P	W	A	S	X	Commission Errors No.	Commission Errors %
J	351	22	22	1	6	53	104	23
P	0	309	95	40	30	20	185	37
W	14	4	196	0	1	120	139	41
A	0	42	39	350	17	30	128	27
S	0	8	1	2	336	27	38	11
X	35	15	47	7	10	150	114	43
	10	10	10	10	10	10	1692	Total Correct
Total Errors	49	91	204	50	64	150	71	% Correct
% Omission	12	23	51	13	16	38		

<u>Legend</u>:

J = Juniper, 341.1
P = Pine, 341.2
W = Mountain Meadows, 315.1
A = Aspen, 342.4
S = Spruce-fir, 341.4
X = Other vegetation types, 390

[1] <u>Omission</u> errors are the percentage failure of interpreters to recognize correct classes.

<u>Commission</u> errors are percentage assignments to a specific erroneous class.

These error patterns reveal the nature of confusion among subjects in image interpretation and suggest points of emphasis in training.

Table 3. Commission-Omission Errors[1] and Accuracy of Interpretations from ERTS Band 7 Black-and-White Images

	Ground Truth						Commission Errors	
PI Calls	J	P	W	A	S	X	No.	%
J	334	49	5	3	56	31	95	22
P	31	291	83	77	4	113	308	51
W	6	9	227	22	1	68	106	32
A	8	41	67	271	9	99	224	45
S	16	3	2	2	315	39	62	16
X	5	7	16	25	15	50	68	58
	10	10	10	10	10	10	1488	Total Correct
							62	% Correct
Total Errors	66	108	173	129	85	350		
% Omission	17	27	43	32	21	88		

Legend:

J = Juniper, 341.1
P = Pine, 341.2
W = Mountain Meadows, 315.1
A = Aspen, 342.4
S = Spruce-fir, 341.4
X = Other vegetation types, 390

[1] Omission errors are the percentage failure of interpreters to recognize correct classes.

Commission errors are percentage assignments to a specific erroneous class.

These error patterns reveal the nature of confusion among subjects in image interpretation and suggest points of emphasis in training.

Table 4. Commission-Omission Errors[1] and Accuracy of Interpretations from ERTS Band 5 Black-and-White Images

PI Calls	Ground Truth J	P	W	A	S	X	Commission Errors No.	%
J	249	53	132	6	2	52	245	50
P	38	259	99	102	59	36	333	56
W	66	6	109	3	5	136	219	67
A	2	63	21	158	106	27	219	58
S	0	11	6	121	218	36	174	44
X	45	8	33	10	10	113	106	46
	10	10	10	10	10	10	1106	Total Correct
Total Errors	151	141	291	242	182	295	46	% Correct
% Omission	38	35	73	61	46	74		

Legend:

J = Juniper, 341.1
P = Pine, 341.2
W = Mountain Meadows, 315.1
A = Aspen, 342.4
S = Spruce-fir, 341.4
X = Other vegetation types, 390

[1] Omission errors are the percentage failure of interpreters to recognize correct classes.

Commission errors are percentage assignments to a specific erroneous class.

These error patterns reveal the nature of confusion among subjects in image interpretation and suggest points of emphasis in training.

tend to have the shape and the color of a mountain meadow, except that a more experienced ecologist would not expect to see many mountain meadows, "W", in the juniper zone, especially not in slope positions. The juniper stands called other, "X", are very probably due to the open stands of juniper which do in fact intergrade into sagebrush (the most extensive community type in the "other" class). Since most of the juniper in this region has a sagebrush understory, it is logical to expect that savanna-like stands of juniper would have a high probability of being misclassified as "other."

Additionally, in the ERTS Band 7 data (Table 3) the reason why juniper was erroneously "called" pine, "P", and spruce, "S", may very likely be due to the equally dark tone of these three images in black-and-white infrared. Had the interpreters been more experienced ecologists and had they been reading the relief correctly, they would have rarely if ever called spruce as juniper because of the elevational zonation difference in the occurrence of the two. Thus may be discovered and rather vividly illustrated an important point for special attention in future training. Knowledgeable readers can similarly derive additional "nuggets" of information from careful study of these tables.

This illustrates the role of comparative interpretation tests not only to document validity but improve training and performance of image interpreters. On small projects the luxury of doing this in a highly formalized way may not be economically justified; but on large projects extending over considerable periods of time, such formal tests can help, as indicated above, as well as provide a method for supervising interpreter performance.

The correct responses were next tabulated from all interpreters in a matrix table and a two-way analysis of variance was performed. The main effects (image type and natural vegetation analog) as well as the interactions were all found to be very highly significant. Results were compared by pairs across the image types using Tukey's method. The results for the combined comparison are summarized in Table 5. Note that in both instances the color infrared images were most accurately interpretable. In summary, this test indicates that for visual interpretation of ERTS or EREP data, color photographic products should be used almost exclusively but with black-and-white infrared images being equally good for some subjects.

9.2 EARTH RESOURCE DISCRIMINATING POWER OF ERTS

The ability of a system to discriminate among subjects of interest is an important determinant of (1) the level at which vegetation analogs may be treated in the hierarchical legend, and (2) the degree to which information relevant to resource decisions can be derived from the system or its various components. We approached the system capability question on a subjective basis by determining the number of image types that could be discerned by interpretation of each ERTS and Skylab image type without regard to identification of the subjects they represented. Such a test is meaningful and valid on the assumption that if one can discern a difference and thus delineate a subject area, there are ways by which it can be accurately identified to provide useful information.

Table 5. Analysis of Natural Vegetation Identification Test By Means of Tukey's Method of Pairwise Comparison

Image Type	PERCENT CORRECT RESPONSES BY NATURAL VEGETATION CATEGORY						
	Pinyon-Juniper	Ponderosa Pine	Sedge Meadow	Aspen	Spruce-fir	Other Natural Vegetation	Average for all Categories
ERTS-5	62	64	27	40	55	28	46
ERTS-7	84	73	*57	68	79	13	62
ERTS Color Composite	*85	77	50	*88	84	38	70
EREP 190A B/W Red	72	59	29	49	58	35	52
EREP 190A B/W IR	*86	70	*55	82	78	12	64
EREP 190A Color	78	73	33	45	57	46	55
EREP 190A Color IR	*91	*92	*56	*93	*91	*50	*79
EREP 190B Color	*91	64	41	53	81	*56	64

Entries in the table above are mean number of correct responses per interpreter. Starred (*) entries within a column fall within a confidence interval of $\pm$ 6 percent response and form an image class which is significantly different from the unstarred entries, and are therefore best for the interpretation of the natural vegetation category which heads that column. The far right column contains the average for all natural vegetation categories. Note that the EREP S-190A Color IR images is for overall interpretive purposes.

To make this comparison, an identical area of approximately 21-square inches was laid out on each image type. From this population, six one-square-inch samples were drawn. To provide direct comparability, the same six locations were used for each image type. Two experienced interpreters examined each square-inch sample and independently decided on the number of image classes that could be discerned within the designated sample area. They first did the "easy to discern" determination, compared results and discussed differences to agree on the number that their collective experience indicated could be repeatedly detected without problems of incomplete boundary location and consistency of recognition. This number was entered as the first observation for the square-inch sample area. They then repeated the process to decide on the total number of image classes that could possibly be discerned in the same sample area by considering subtle differences in density, color or image texture. Notes were compared and a single decision again reached on the maximum number that could be practically interpreted in an operational setting; i.e., entire boundary definable and reasonable expectation that interpreters, working under the same set of mapping intensity guidelines, would be able to recognize each image type.

The average number of classes discerned in the six square-inch sample areas is tabulated in descending order (based on film type) in Table 6.

These data enable a comparison of color versus black-and-white. For the "easy discernability" class, color defined 38 percent more kinds of images than black-and-white and 50 percent more for the total possible "class."

Table 6. Number of Classes Discerned by Image Type.
Mean of Six-Square-Inch Sample Areas

Film Type	Average Number of Image Classes	
	Total Discerned	Easily Discerned
S-190A CIR	50	41
S-190B Color	40	29
S-190A, Band 5	36	24
ERTS CIR	31	29
ERTS Band 5	30	19
S-190A Band 7	25	19
ERTS Band 7	24	21

In summary, the following can be said about the interpretability of natural vegetation analogs from ERTS-1 photographic products.

a. Color infrared is substantially better than black-and-white from any band.

b. There is a consistent suggestion that among the black-and-white bands ERTS Band 7 is slightly better for vegetation interpretation than Band 5. On the basis of the number of discrete mappable image areas within several sample areas, the ERTS color composite was best, Band 5 second, and Band 7 third (see Table 6).

c. Formal interpretation testing provides essential information for training and interpreter supervision on large projects.

d. Given a level of legend interpretation that is consistent with the quality of the imagery, ERTS-1 color infrared reconstituted images can be ocularly interpreted with accuracy sufficient for broad-scale vegetation inventories provided some ground checking is done before results are finalized. With proper ground truth knowledge, most dense vegetation can easily be interpreted to third or fourth level; and sparse vegetations can be interpreted to second and often third level. The savanna-like class, 330, is the single most difficult class; it can only be inferred from knowing what to expect and subtle indications of associated and convergent evidence. It will usually be called an herbland, 310, or a shrubland, 320. In these test areas, the savanna-like juniper stands were the most troublesome.

10.0 QUANTIFICATION OF VEGETATION ANALOGS BY DIGITAL DATA ANALYSIS

Even though this project was designed and funded to work only with conventional interpretive methods and the photographic products from ERTS, we have been well aware of the potential superiority of the MSS data for image quantification and characterization--particularly in the intra- and interregional context. The Principal Investigator did some work i.. the late 1960's with the Michigan 18-channel scanner data in the semi-arid rangeland environment. In fact, one of his test sites was on the east edge of our current Sierra-Lahontan Test Area. This work clearly demonstrated that the best and most accurate way to quantify the multispectral signatures of remotely sensed rangeland resources would be with a multispectral scanner system in the hands of one who knows the ecology of the landscapes used for testing and development. At the same time, we were working enough with the early Gemini and Apollo space photography to become fully aware of the problems of maintaining image consistency with photographic products--particularly with color and color infrared films. In spite of this prior experience we chose emphasis on the photographic product because: (1) it is a product that everyone can learn to use even in remote field offices, and (2) it does not require the expensive computer support capability that the MSS system does when analyzed in the digital tape mode.

On the other hand, if one expects to develop MSS analyses of range and forest landscapes that are managerially significant--relevant to the information needs of resource management decision makers--one must take an approach that eventually classifies to the fifth or sixth level in our unified legend system. An opportunity to test this idea came when,

through another project, we were able to collaborate with IBM; we assisted them to attain some of their goals in software and analytical methods development by providing a test area and ground truth from our ERTS project at no computer or related costs to this project. We took the opportunity and worked with Robin Mowlem of IBM in Gaithersburg, Maryland, and Mike Hord of EarthSat, Washington. We ran some digital analyses on one tape supplied by NASA for ERTS scene 1003-18170 acquired on 26 July 1972. Two test areas were analyzed, one north of Honey Lake in California (shrub steppe, legend class 325) and one west of Honey Lake in a transition between shrub steppe and forest (341/343). This latter area also included some rockland (130) and a substantial component of agricultural cropland (500). This gave us the first definitive clue (at that point in the ERTS investigations) of the ultimate refinement and information content obtainable from ERTS MSS data.

The two areas analyzed are shown in Figure 17, north of Honey Lake, B, and on the west shore of the Lake, A. Grey-scale printouts were used to outline training sets in both areas and a complete LARS-type classification was made.

On the north shore six classes were distinguished as indicated in Figure 18. They are identified as follows:

Red areas (see Figure 18) on the color coded printout indicate agricultural fields.

Green areas are dominated by big sagebrush (Artemisia tridentata) with cheatgrass (Bromus tectorum) occurring abundantly in the understory. At the time of imaging, however, the cheatgrass was dry. Soil was

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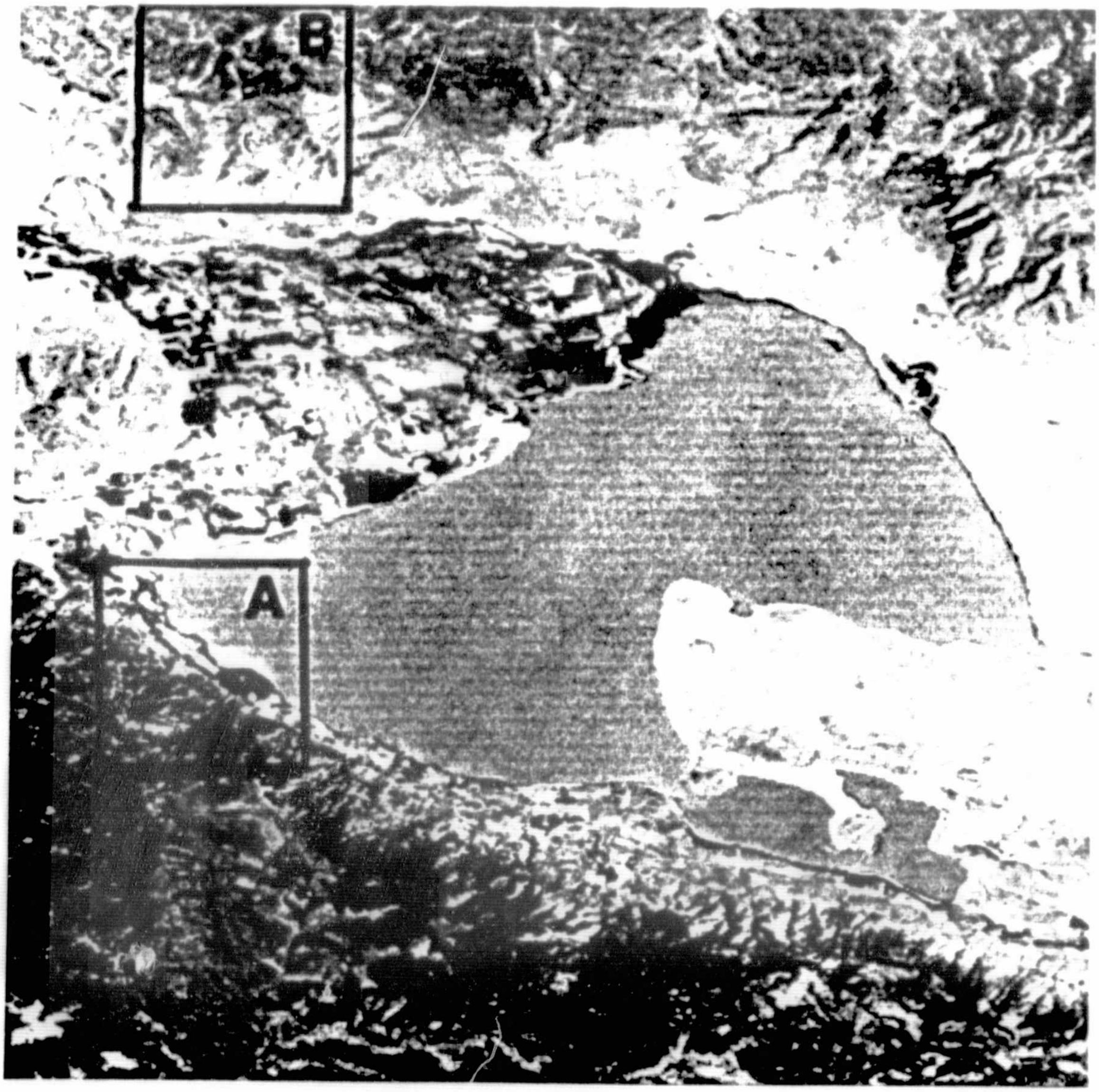

Figure 17. The two digital data analysis test sites near Honey Lake, California. West Shore is A; and North is B. Sierra-Lahontan Test Area. This is an enhanced Litton print of band 5 from ERTS scene 1003-18170 acquired 26 July 1972.

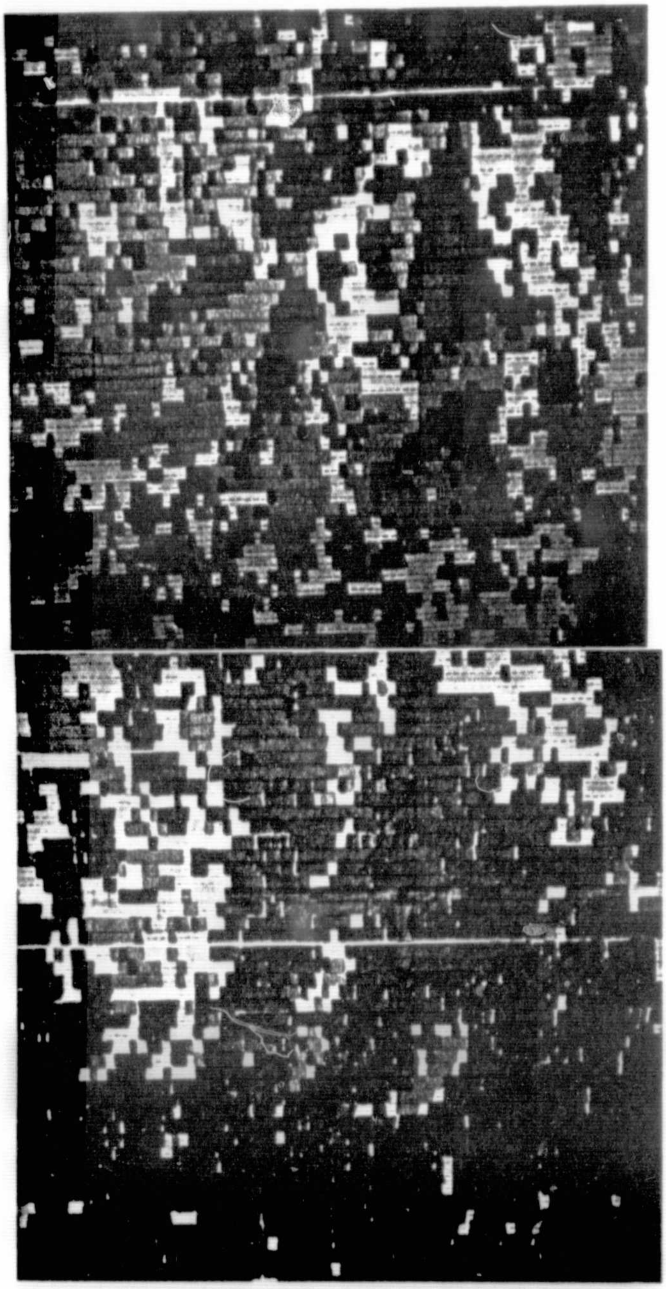

Figure 18. Classification: North Shore, Honey Lake, California. ERTS-1003-18170, 26 July 1972. Red = agricultural fields; green = big sagebrush with heavy stand of dry cheatgrass in understory; blue = mixed big sagebrush-bitterbrush on rocky ridges; purple = bluebunch wheatgrass, sandberg's bluegrass stands; white = unclassified but mostly rock outcrops; yellow and orange = upland drysite sagebrush with the yellow-orange difference related to stand density and soil stoniness.

moderately deep and sandy. Thus the soil characteristics unique to this ecosystem make a significant contribution to the image during the dry season when little annual brome is covering the ground surface.

Blue areas indicate mixed big sagebrush and bitterbrush (Purshia tridentata) on slopes and rocky ridges above the moderate slopes that support pure big sagebrush. Bitterbrush is an important browse species. Detection of this ecosystem is particularly important in management.

A marked break in slope and change in species composition are indicated by yellow and orange areas. These areas have moderate-to-steep slopes with high percentages of open, rocky ground. Vegetation types appear to be essentially the same on the yellow and orange areas. Artemisia tridentata ssp. xericensis, a low-statured variety of big sagebrush, is dominant on these areas with large amounts of Sandberg's bluegrass, and needlegrass along with other semi-desert annual species. The main differences between the yellow and orange areas are the stand density of sagebrush and stoniness of the soil surface.

Purple areas include extensive areas dominated by bluebunch wheatgrass (Agropyron spicatum), an important perennial bunchgrass. These areas are visually identifiable on ERTS imagery while the other types are much more difficult to distinguish visually. The bluebunch wheatgrass stands are also highly important to differentiate for management purposes because of their particularly high grazing value and capacity.

The white, unclassified areas outside of the crop fields all turned out to be rock outcrops for which we had not provided a training set.

In the test area north of Honey Lake we were surprised at the degree to which individual vegetation-soil systems were classifiable. Even though this classification is not perfect, it clearly shows the potential for extracting information appropriate to moderately intensive management from the ERTS data. The above differentiations are at fifth level in our legend system, and the yellow-orange differentiation is at sixth level.

Figure 19 shows a multispectral plot for the subjects classified in Figure 18. The letters locate the means and the asterisks define one standard deviation in the training set data. The classes listed refer to individual colors on the actual classification (Figure 18). Class A represents the signature for water taken from the same tape just south of this test area on the north shore of Honey Lake. Class B refers to the red areas in Figure 18; Class C refers to the blue areas; Class D refers to the green areas; Class E refers to the orange areas; Class F refers to the yellow areas; and Class G refers to the purple areas.

Table 7 demonstrates the success with which individual picture cells indicated in the training classes were classified into the correct vegetation types. Had we time and funds to refine the training sets, an even better classification and map would be possible.

A classification was also attempted on the west shore of Honey Lake (area A in Figure 17). This area presented more subtle and intricate vegetational variation. It is covered by coniferous forests, small areas of shrublands, some rock outcrops and agricultural fields. Training set selection was extremely difficult without the aid of larger scale

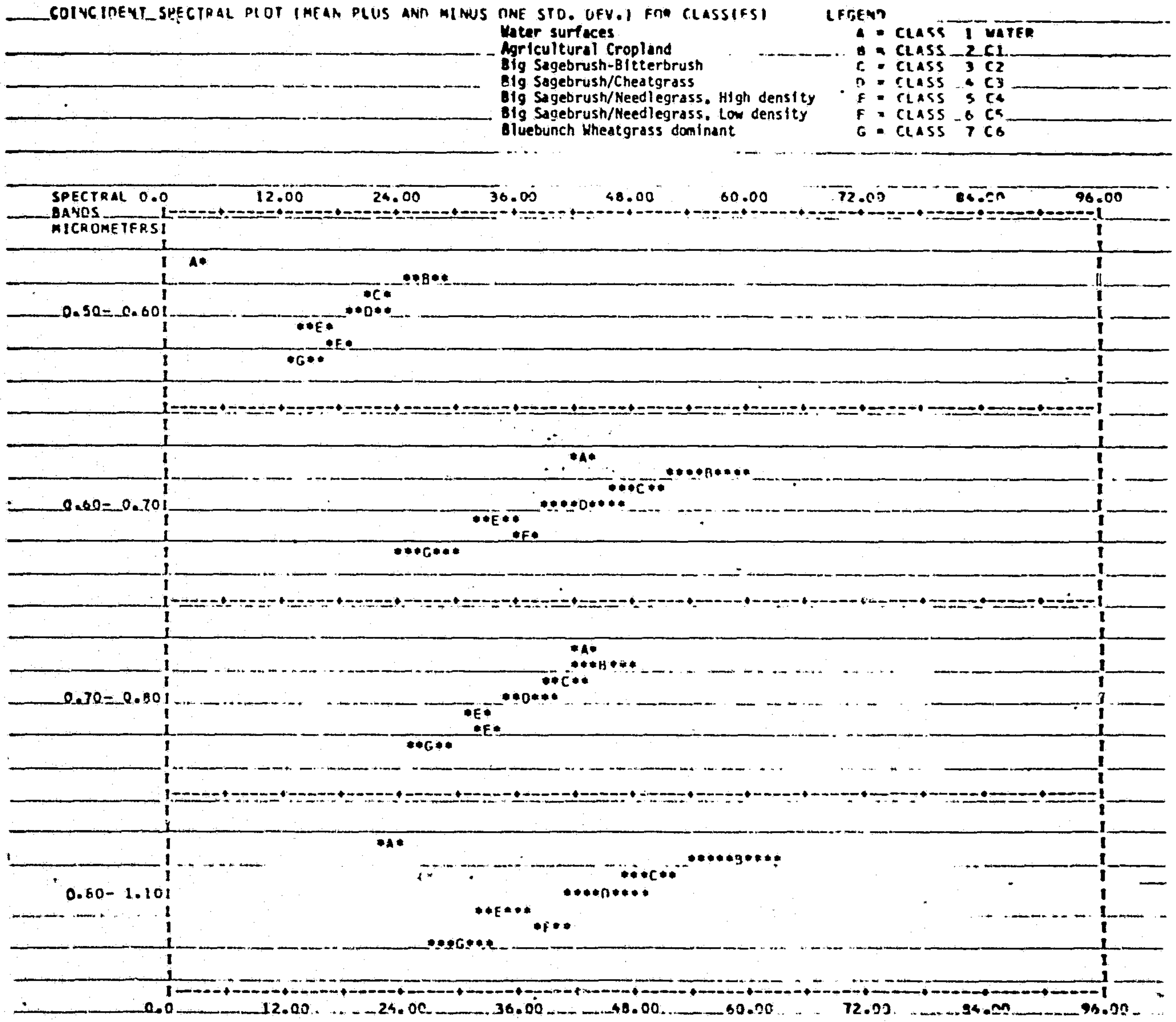

Figure 19. Multispectral Plot, North Shore, Honey Lake

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Table 7. Training Class Performance

Legend

Class		Description
2	C1	Agricultural cropland
3	C2	Big sagebrush-bitterbrush
4	C3	Big sagebrush/cheatgrass
5	C4	Big sagebrush/needlegrass, high density
6	C5	Big sagebrush/needlegrass, low density
7	C6	Bluebunch wheatgrass dominant

Number of Samples Classified Into

Class		Number of Samples	Percent Correct	Water	C1	C2	C3	C4	C5	C6	Threshold
2	C1	54	90.7	0	49	5	0	0	0	0	0
3	C2	192	86.5	0	6	166	20	0	0	0	0
4	C3	62	79.0	0	5	7	49	0	1	0	0
5	C4	68	86.8	0	0	0	0	59	8	1	0
6	C5	69	94.2	0	0	0	1	3	65	0	0
7	C6	167	95.2	0	0	0	1	6	1	159	0
TOTAL		612		0	60	178	71	68	75	160	0

Overall performance (547/612)=89.4 Average performance by class (532.4/6)=88.7

photography. Some of the training sets turned out to be quite heterogeneous mixtures of vegetation types, plant density patterns, rock outcropping, and other variables. Thus the first classifications attempt in this area did not reflect vegetative community patterns at much better than tertiary legend level. Table 8 shows the training class performance on this attempt. While these results look good, we were unable to define training sets for many of the important vegetation differences in the test area.

The run did separate agricultural land from nonarable land, and picked one meaningful subclass within agriculture. It differentiated two classes of forest seemingly related to density of coniferous forest cover or proportion of oak, and left unclassified an area that was predominantly rockland outcrops, legend 130. If one examines the multispectral plots of Figure 20, the problem is evident in the strong overlap among some classes and the great variability in many of the training sets. Examination of the histograms for the variable sets showed bimodal distributions in many cases, thus confirming that the problem was with training set selection--no easy task in many ecologically complex areas of natural vegetation. This area and trial run are typical of the difficulties we anticipate will frequently be encountered as people attempt digital analysis in environmentally complex areas. The problem is not, however, with the system but rather with the extreme difficulty of designating pure training sets from the multiband computer printouts. This problem can be solved by use of support photography and enlarged Litton prints of the specific scene area.

Table 8. Training Class Performance, Digital Analysis of West Honey Lake Test Area

Extremely complex forest and rangeland example. While training sets were quite good and homogeneous, a satisfactory classification was not achieved in two different runs with LARSYSAA VERSION 2.

Legend

Analog	Class	
Water Surfaces	1	Water
Abandoned agricultural land and harvested crops	2	L1
Green crops, alfalfa	3	L2
Jeffrey pine/shrub (dissected mountain slope complex)	4	L3
Jeffrey pine-oak/shrub (riparian and protected, undissected mountain slopes)	5	L4

Number of Samples Classified Into

Class	Number of Samples	Percent Correct	Water	L1	L2	L3	L4	Threshold
1 Water	221	100.0	221	0	0	0	0	0
2 L1	36	80.6	2	29	4	1	0	0
3 L2	36	91.7	0	3	33	0	0	0
4 L3	110	95.5	0	4	0	105	1	0
5 L4	60	100.0	0	0	0	0	60	0
Total	463		223	36	37	106	61	0

Overall performance (448/463)=96.8 Average performance by class (467.7/5)=93.5

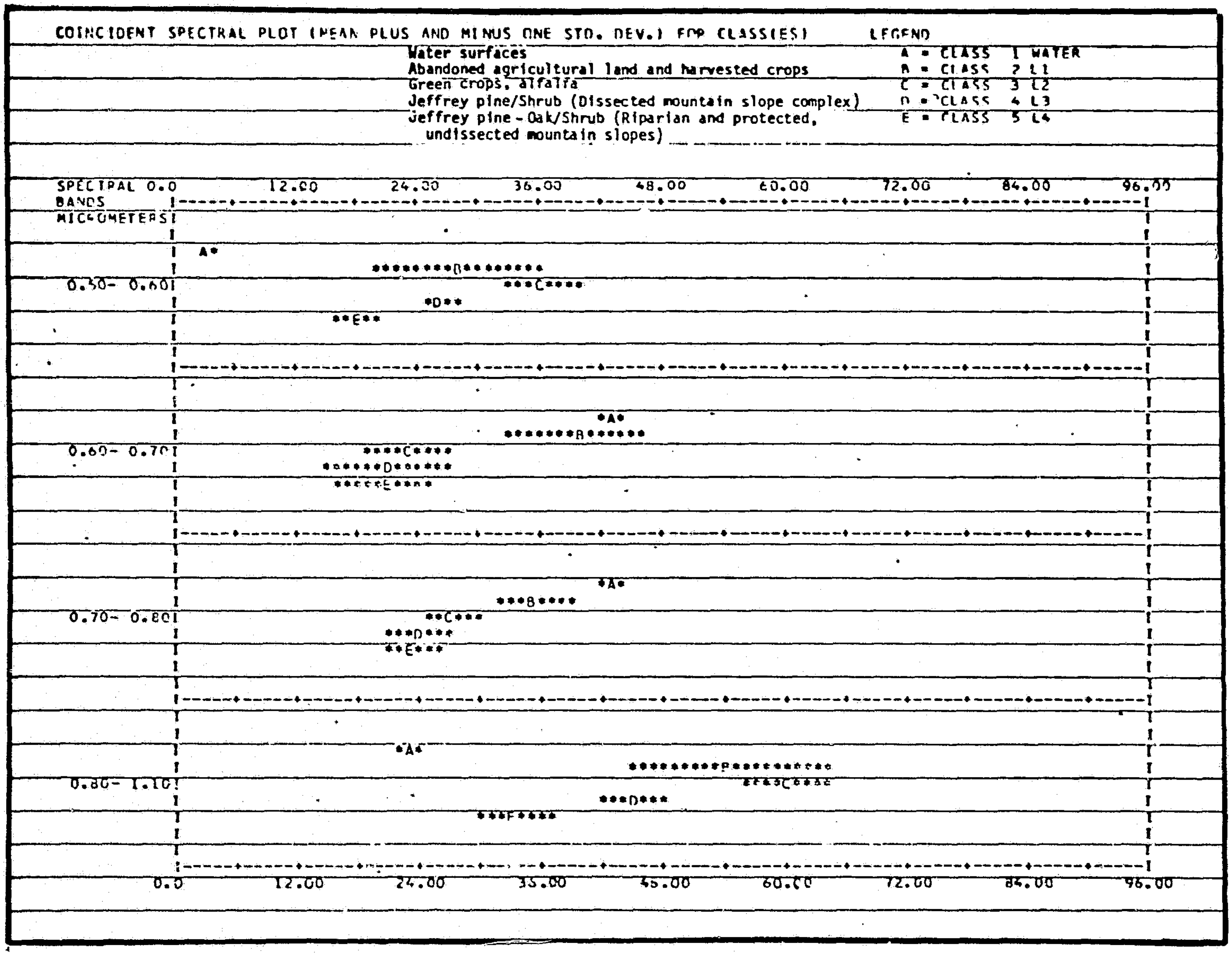


Figure 20. Multispectral plots, West Shore, Honey Lake.

For application of ERTS digital data analysis to naturally vegetated landscapes, where the need is for maps and statistical tables of kinds and amounts of resources, this and other experience leads us to suggest a few considerations of practical significance as described in the following paragraphs.

In using ERTS data to solve problems in vegetational resource management, the first step should be to perform a conventional human photo interpretation job. This enables one to make efficiently a broad classification of the landscape and resources--usually to second or third, and occasionally to fourth, legend level. This process clearly identifies areas that are in low priority, and also those in high priority, for further and more intensive analysis. At this point one has two options: (a) to go to digital data analysis where one can consider the landscape at scales of approximately 1:24,000 and landscape units of one pixel or approximately 0.4 ha.; or (b) to go to multistage aerial photographic analysis. This kind of approach with either of the options has maximum chance of being cost-effective across wide regions. In our opinion, the digital analysis of entire scenes as the first step is entirely unreasonable because of (a) cost, and (b) the highly detailed understanding of landscape features that this system requires. Such understanding is often not available among the support personnel or in the scientific community.

For quantification of the spectral signatures of intra- and inter-regional analogs, digital data analysis is really the only efficient and entirely effective approach. The highest fidelity spectral signatures of any given resource subject (in the natural resources management context)

are obtained by a scanner system as recorded on tape. In addition, we hold the position that the best and most cost-effective way to establish the spectral recognition signatures for purposes of landscape classification and analysis is by the operational system itself functioning from anticipated altitude. In no other way can one accurately integrate the combined signatures of a multitude of plant species, bare soil surfaces, rocks, and ground litter into a single integrated signature that truly represents a specific ecosystem or vegetation-soil analog as it will be seen by that system. The writers maintain strong support and preference for this approach to signature definition and for the development of signature banks that could hopefully be used interregionally. In making this statement we are thoroughly aware of the success some have had in computer modeling composite signatures from known reflectance values of most of their components.

When one considers the tremendous number of ground, or even "cherry picker," multispectral reflectance measurements one would have to make in the natural landscape in order to have the essential inputs for signature modeling of natural ecosystems, the task exceeds the bounds of reasonableness and economic feasibility. The concept of defining these same ecosystem signatures by overflying well-documented and representative test areas is a far superior approach.

The approach we have demonstrated here would actually be the best way to perform a quantitative test of the hypothesis of interregional vegetation analogs. Our work has qualitatively supported the hypothesis, but is weak in quantification. In addition, the approach we have demonstrated and discussed in this section of the report could be a most

effective way to develop natural ecosystem signature banks that would be applicable over a very wide region--possibly even globally for the highest hierarchical levels and certain selected subjects that are truly global in extent. Such is the only practical approach by which such a goal could be approached or achieved assuming, of course, that it is a desirable goal or benefit to mankind through an Earth Orbital Sensor System.

11.0 SIDE-LAP STEREO INTERPRETATION OF ERTS-1 IMAGERY

Starting with Apollo VI photography in southern Arizona, the Principal Investigator and his associates began to consider the possible advantages of stereo viewing of space imagery when interpreting vegetational and other earth resource features. These initial experiences were most encouraging and were further strengthened from stereoscopic examination of part of the S065 experimental photography from Apollo IX. Naturally some of our interest in the ERTS-1 data turned to further studies and trials of the usability of these new data in either a true stereo or binocular reinforcement mode when interpreting vegetational features.

One's capability to interpret vegetation from any kind of overlapping imagery that allows three-dimensional viewing is greatly increased if one knows elevational and latitudinal zonation patterns and also understands the vegetation-landform relationships in the areas of interest. Thus when one can examine an image and at the same time see from a three-dimensional perspective where that subject lies on the landscape, a very powerful kind of associated evidence becomes available in making image identification decisions. It is with the idea of optimizing interpretability by the human that our interest in stereo viewing from space persists. Thus, one of the first things we examined upon receipt of both RBV and MSS imagery from ERTS-1 was the possible enhancement of interpretability of these new systems by exploiting binocular reinforcement and the three-dimensional perspective. The results of this initial work were reported at the

29 September 1972 ERTS-1 investigators' briefing conference at GSFC, and subsequently published with full color illustrations from Apollo VI and black-and-white Band 2 and 5 images from ERTS-1 in the proceedings of the conference. At that time we urged NASA to continue to obtain up to 60 percent side-lap on adjacent orbits at northern latitudes and suggested that other investigators interested in natural vegetation, geology, and landforms also take advantage of this capability. In flat country, the advantage comes only from binocular reinforcement, but even this is significant. In strongly rolling to hilly relief, the gain in reinforcing the tone patterns is significant; in mountainous terrain it is very substantial in this respect and also provides adequate stereo parallax for viewing the terrain three-dimensionally.

In our Sierra-Lahontan Test Area, between latitude 38° and 40°N, ERTS-1 initially gave us slightly over 50 percent side-lap. Subsequent to the 28 August 1972 orbit adjustment we obtained some 46 percent side-lap imagery and it settled down to average about 34 percent in our two test areas. This high percentage of side-lap is a tremendous asset if fully exploited in interpretation and, of course, some of those working farther north can have the benefit of full stereo coverage. At our working latitude, only about 34 percent of the landscape was not imaged in stereo. By studying the side-lap areas on either side of a scene, one's ability to interpret the intervening one-third is significantly improved if there is discernible relief in the bordering stereo models. Even in flat-to-undulating country, however, there is an advantage from binocular reinforcement when viewing two different scenes simultaneously. Especially since color balance normally differs

between the two, these differences are sometimes reinforcing so that the integrated image seems to enhance vegetation and/or soil boundaries.

An additional advantage comes from binocular viewing where considerable time has elapsed between the two scenes--either in the context of land use change or vegetational change brought on by the seasons. By alternately blinking each eye or passing a grey card back and forth to alternately obstruct one field of view and then the other, image areas that have changed will appear to shift from one color or density level to another. If one does not have a suitable comparative viewer, it is much easier to compare scenes in this way then to separately view the two while trying to maintain locational orientation. If one is concerned about temporal change, the entire image area can be examined in this way, not just the stereo side-lap region. In the absence of sophisticated equipment like zoom transfer scopes, this is an effective quick-look method for locating areas of change after which one can use techniques like positive-negative color combining to bring out all of the areas of change in the scene.

We conducted some photo image interpretation tests with 10 student interpreters, each making 10 interpretation decisions about six natural vegetation subjects. Four of the subjects were designated at quaternary legend level, one at tertiary level, and one at primary level, the latter being a catch-all "others" class. These interpreters first performed the test by monoscopic examination. After a substantial delay, they were given the same test with a stereoscopic model. For this group the monoscopic interpretation was 82.7 percent correct, and surprisingly, the stereoscopic interpretation was only 77.0 percent correct; however, the

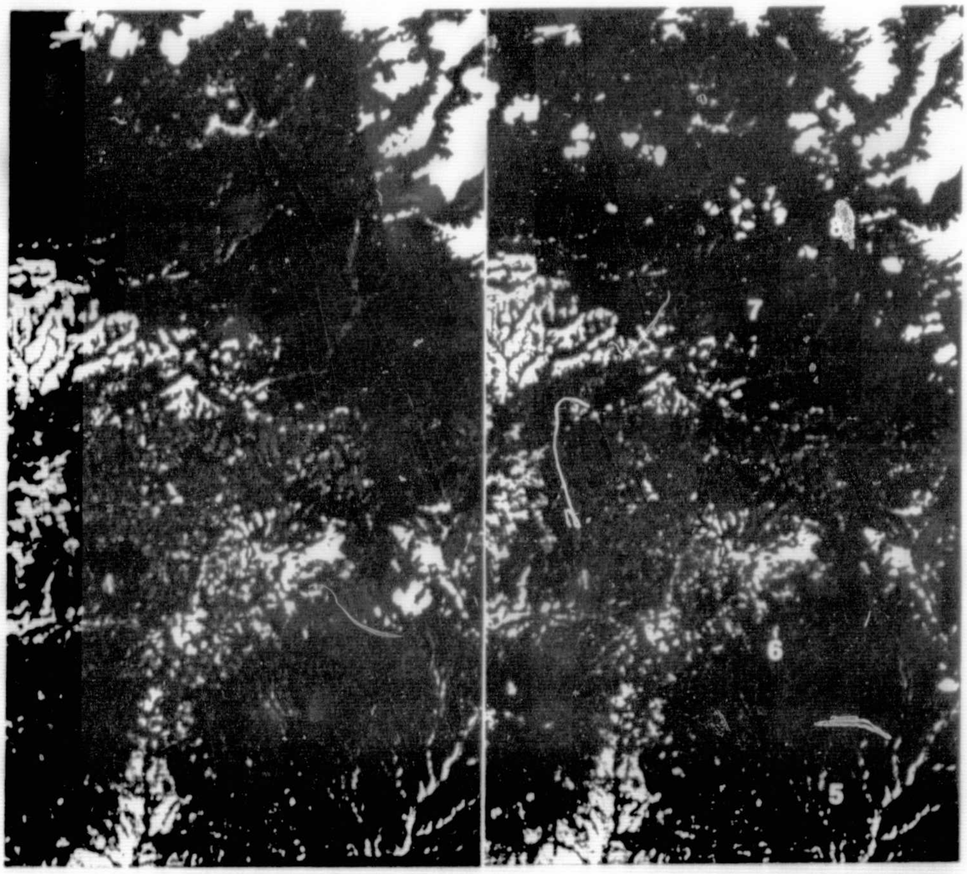
difference is not significant on the basis of a paired (P=.01) test. If one looks at the individual student results, 4 of the 10 students did definitely better on stereo interpretation than monocular; and two of these students classified four of the six subjects without error in stereo interpretation. Only one of the ten students classified four subjects without error in the monocular test. Statistically speaking one cannot say, however, that this test showed an advantage to stereo interpretation. This surprised us because our hypothesis was for an advantage to stereo viewing. The following may be an explanation for the failure to show a significant difference: (a) all of the test subjects were students currently in their first course in aerial photo interpretation and, without exception, the course was the first exposure any of them had had to the subject; (b) although all of the students had unimpaired stereo vision, none had spent extensive periods of time engaged in stereoscopic interpretation, and; (c) perhaps most significant of all, none of the students had had experience in field ecology or in relating vegetation to the landscape of a stereoscopic model. At the beginning of the test period all student testers were given an illustrated lecture on the natural vegetation of the test region, the normal zonation patterns, and what they could expect to find. In no case, however, was this presentation related to, or compared with, the imagery they were to examine.

We did not have funds to conduct a second test with experienced interpreters, but one of our experienced staff members did perform the test. His total correct was 67 percent on monscopic interpretation, and none without error. He had 82 percent correct on stereoscopic, with

three classes perfect and two classes 70 percent correct. Another of our experienced interpreters did the stereo test only. He classified 80 percent correct with three classes perfect and one of the six classes 90 percent correct.

In summary, perhaps the best we can say for vegetational interpretation by stereoscopic examination of space imagery is that experienced interpreters make more accurate identifications of vegetational subjects with stereoscopic interpretation and that some especially adept beginning interpreters, with careful training, can do equally well or better and they also do their best with stereoscopic interpretation.

A stereo model of our primary test area in the Colorado Plateau Region is presented in Figure 21. This model was interpreted both monocularly and in stereo. It is the area in which the stereoscopic tests referred to above were conducted. One cannot begin to map as pure types the amount of detail that can be interpreted at the scale of this illustration, approximately 1:634,000. The entire model has mapped, at a scale of 1:250,000. This mapping produced 49 delineations averaging 36 sq. km. each. Of these, 50 percent were pure types and 50 percent were complexes of two different but identifiable analogs. The model was interpreted in 125 man-minutes at a cost of seven minutes per 100 square kilometers. While this season (Scenes No. 1299-17205 and 1300-17263 acquired on 18 May 1973 and 19 May 1973, respectively) is not optimum for mapping the upper elevation forest types it is ideal for the arid shrubland types and for separating dryland from irrigated agriculture. Some ground-confirmed image types are identified on the stereo model. Readers are encouraged to examine these to learn first-hand about some of the potentialities and limitations of stereo viewing



1 = 324 - Salt Desert
2 = 311 - Annual Grassland
3 = 315 - Meadows
4 = 325.1 - Sagebrush Steppe
5 = 341.1 - Juniper/Sagebrush
6 = 341.12 - Juniper/Oakbrush
7 = 341.2 - Ponderosa pine
8 = 347.1 - Oakbrush

Figure 21. An example of stereo coverage from ERTS-1 in color reconstituted infrared form. This illustration is taken from ERTS frame 1299-17205 (right-hand) and 1300-17263 (left-hand). The images were acquired on May 18, 1973 and May 19, 1973, respectively. First examine these illustrations monocularly and then in stereo. Notice how landform relationships that may have been in doubt in the former case are clarified in the latter.

interpretation of space imagery. Thus, one has two choices: (1) to increase the level of generalization in the legend used, or (2) to identify delineations as complexes of more than one legend component. Preliminary to choosing either of these alternatives, however, one must decide on the scale of imagery that will be appropriate to solution of the problem at hand. At what minimum scale can the information needs be met? At some point in information requirement, one must recognize that a particular image type (or system) and a specified scale is not adequate for meeting the level of detail that the proper solution requires. At that point, scale must be increased or the system changed.

Different purposes or uses demand different approaches to this problem. For information that is to contribute to policy and broad planning decisions, the tendency would be to generalize the legend. Where more specific decisions or actual allocations of resources are to be made, the tendency would be to map in complexes by identifying the various components as to legend unit and indicating the proportion of the delineation area occupied by each component. This assumes, of course, that the proper scale decision has already been made. If it has, the percentage of delineations treated as pure types will be large, and the proportion of complexes relatively small.

One of the most significant findings to come out of this test of stereoscopic interpretability is the fact that both beginning and experienced interpreters can be trained to identify correctly vegetational subjects at tertiary and quaternary levels in our unified legend system, whether they are using monoscopic or stereoscopic examination of the imagery in reconstituted color infrared form. The significance of this

is best recognized if one is reminded that the quaternary legend level recognizes the genus of the dominant component in the vegetation in most cases; i.e., it is the first floristic level at which point the information begins to take on a degree of local significance in management. It must be emphasized, however, that no one can identify ERTS images at this level unless he knows what to expect and has considerable ground truth information. The better he understands the zonational and vegetation-landform relationships in the subject area, the more reliable will be his interpretation. Even given all this, the best interpreters will make some errors. A few vegetation types will be identified with very high reliability, 90 to 100 percent, and others with only 60 to 80 percent reliability.

12.0 VEGETATIONAL PHENOLOGY AND MULTIDATE IMAGERY

Table 1 lists all of the vegetation and environmental analogs that we have identified according to our uniform legend system in each of our test sites. From among these we selected eleven vegetation analogs for potential interregional study (Table 9). We also identified nine additional widespread vegetations that, while they did not occur in both of our test sites in large enough stands to be used in interregional comparison, do occur in other regions of the United States, in stands of sufficient size to be recognizable from ERTS imagery (Table 10).

Our working hypothesis is "given comparable phenological development, vegetation-environment analogs should have comparable spectral signatures and, therefore, be intra- and interregionally identifiable from ERTS-1 photographic products, assuming, of course, consistency of processing."

A major factor which must be considered when assessing the phenological development of montane, subalpine and alpine vegetation communities is snowmelt pattern. Phenological development is directly related to the amount of time available for growth after release from the snow pack and the buildup of soil and microenvironmental temperatures above the threshold for plant growth. Because rate of snowmelt is easily discernible on ERTS-1 imagery, it can be used as an environmental index to choose the best image dates for each test area to allow interregional analysis of the selected vegetation-environment analogs with minimum difference due to plant growth and development.

Table 9. Interregional Vegetation Analogs Successfully Identified on ERTS-1 Imagery

Legend Symbol	Type	Differentiation Level[1] (Legend Class)
315.1	Cyperaceous (Sedge and sedge-like plants)--graminaceous (grass meadows)	Quaternary
324	Salt Desert Analogs: *Sarcobatus* (Greasewood), *Atriplex* (Saltbush), *Eurotia lanata* (Winter-fat), *Dalea* community types	Tertiary
325.11	*Artemisia tridentata* ssp. *tridentata* (Big sagebrush) communities	Quaternary
325.12	*Artemisia arbuscula* (Low sagebrush) communities	Quaternary
327.3	*Salix* (Willow)--*Alnus* (Alder) riparian communities	Quaternary
328	Alpine dwarf--shrub/herb communities	Tertiary
341.1	*Pinus edulis*--*Juniperus osteosperma* (Pinyon pine--Utah juniper) communities	Quaternary
341.2	*Pinus ponderosa* (Ponderosa pine-Colorado Plateau), *Pinus jeffreyi* (Jeffrey pine--Sierra Lahontan) communities	Quaternary
341.3	*Abies concolor* (White fir)--*Pinus ponderosa* or *P. jeffreyi*--*Pseudotsuga menziesii* (Douglas fir) communities	Quaternary
342.4	*Populus tremuloides* (Aspen) communities	Quaternary
342.3	*Populus* (Cottonwood) riparian communities	Quaternary

[1] Tertiary is the third physiognomic level of classification of the vegetation analogs and Quaternary is the first level at which floristic criteria are brought into the classification process.

Table 10. Intraregional Vegetation Analogs Successfully Identified on ERTS-1 Imagery

Legend Symbol	Type	Differentiation Level (Legend Class)[1]	Region
313	Alkali playas (*Salicornia*, *Suaeda*, *Frankenia*, *Allenrolfea*--extreme salt tolerance)	Tertiary	Sierra-Lahontan
325.13	*Artemisia nova* (Low sagebrush) communities	Quaternary	Sierra-Lahontan
326.1	*Arctostaphylos patula* (Manzanita)--*Ceanothus velutinus* (Tobacco brush) *C. prostratus* (Squaw carpet) chaparral communities	Quaternary	Sierra-Lahontan
326.5	*Cercocarpus ledifolius* (Curleaf mountain--mahogany) communities	Quaternary	Sierra-Lahontan
327.1	*Quercus gambelii* (Gambel's oak)--*Symphoricarpos* (Snowberry)--*Amelanchier* (Serviceberry) communities	Quaternary	Colorado Plateau
341.3	Mixed coniferous forest (*Abies*--*Pinus*--*Libocedrus*)	Tertiary	Sierra-Lahontan
341.4	*Picea engelmannii* (Engelmann spruce)--*Abies lasiocarpa* (subalpine fir) communities	Quaternary	Colorado Plateau
341.5	*Pinus contorta* (Lodgepole pine) forest	Quaternary	Sierra-Lahontan
343.1	Spruce-fir/Aspen seral communities	Quaternary	Colorado Plateau

[1] Tertiary is the third physiognomic level of classification of the vegetation analogs and Quaternary is the first level at which floristic criteria are brought into the classification process.

To make this study, each of 15 ERTS-1 frames were color combined (Bands 4, 5, 7) on an additive color viewer for the Sierra-Lahontan Test Area, and each of 14 for the Colorado Plateau Test Area. The criteria used for selecting each frame were (1) maximum number of cloud-free dates, and (2) whether the frame included suitable elevational range. Mean elevation of the snow line was determined for each date using ERTS-1 imagery and topographic base maps. Figure 22 shows the results of this analysis.

Notice in Figure 22 that snowmelt at comparable altitudes in the spring of 1973 was about 15 to 25 days earlier in the Colorado Plateau Test Area than in the Sierra-Lahontan. For a given elevation and thus vegetational zone imagery dates should be selected for approximately the same elapsed time after snowmelt in each of the regions when making interregional interpretations or image comparisons. Selections can also be confirmed and improved by comparison of flush of greening in ephemeral vegetations at lower elevations (Figures 23a, b, c); but at higher altitudes, the rate of snowmelt enables one to predict equivalency of phenological stage quite effectively. A similar technique has in fact been used by range managers to predict the dates when mountain ranges would be ready for grazing. These same kinds of ERTS observations could be used for that purpose as well in mountainous regions.

As an example, shrub steppe ranges that are known to have a heavier grass herbaceous understory can also be mapped more accurately from spring imagery than from dormant season images. On the other hand, differentiation of juniper and pinyon-juniper from sagebrush steppes is not as easily done on spring imagery as it is in the dormant season.

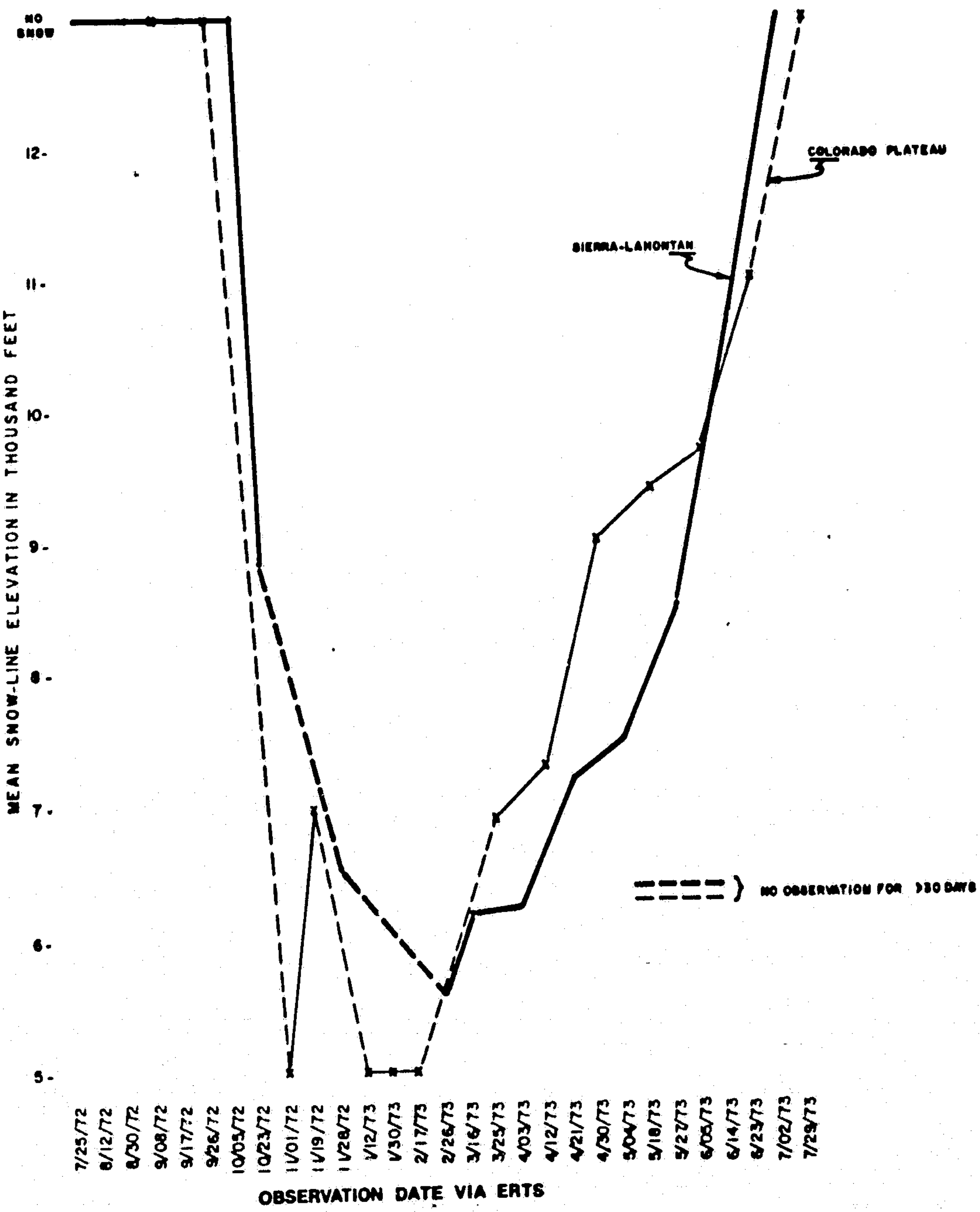


Figure 22. Snowmelt Patterns in Two Regional Test Areas.

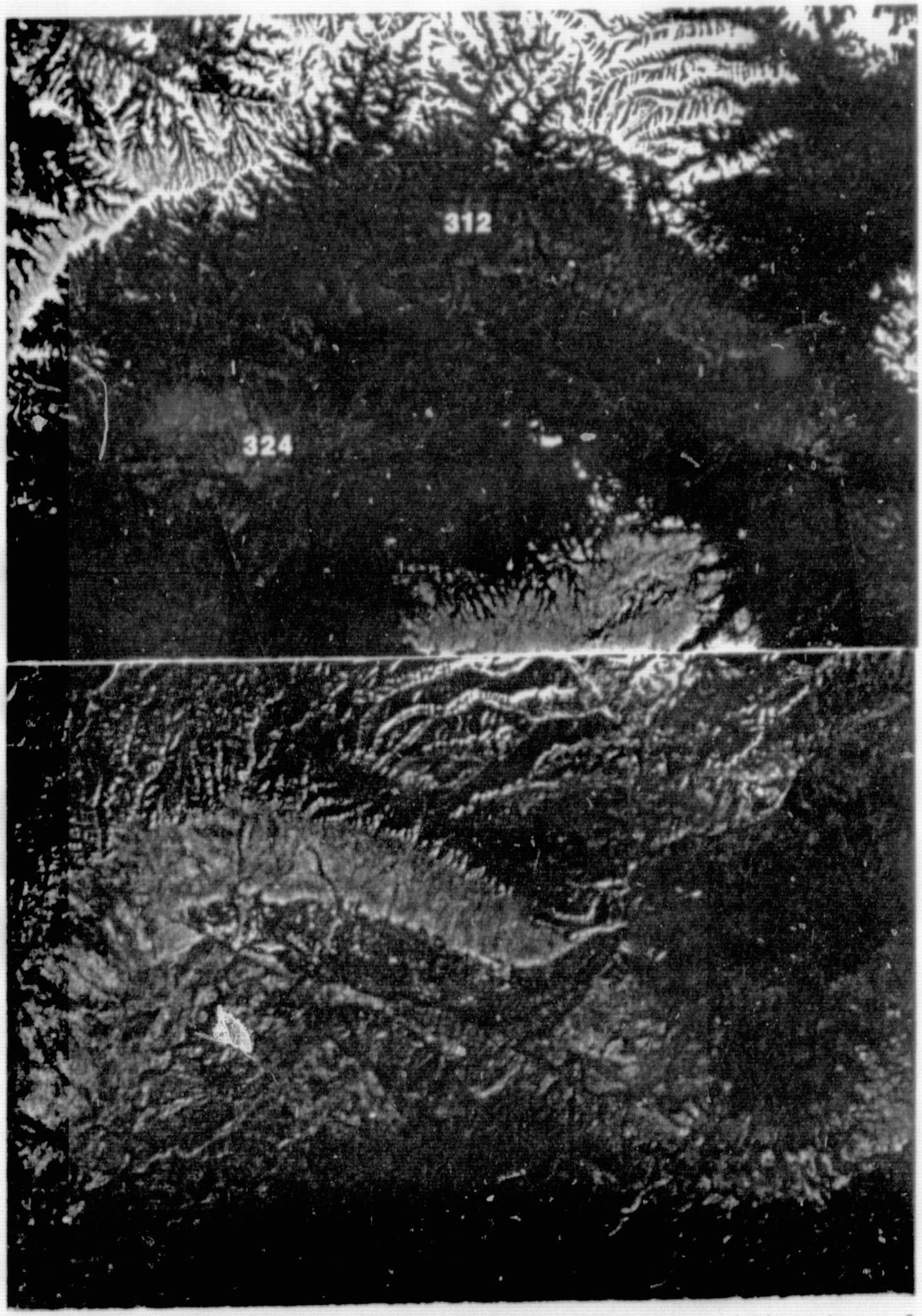
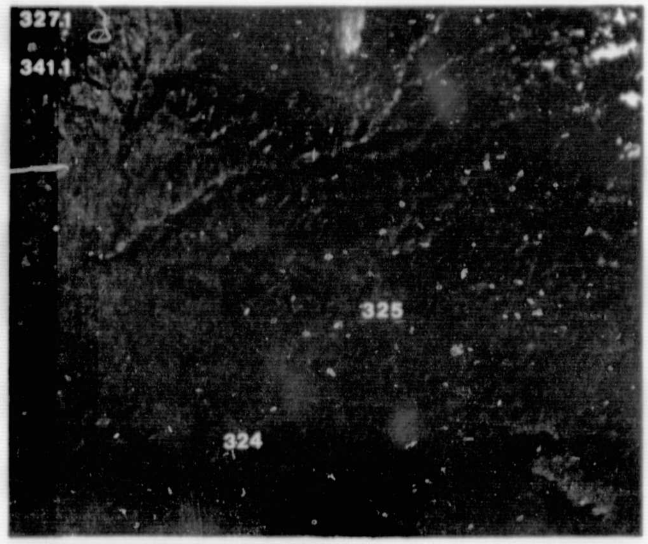
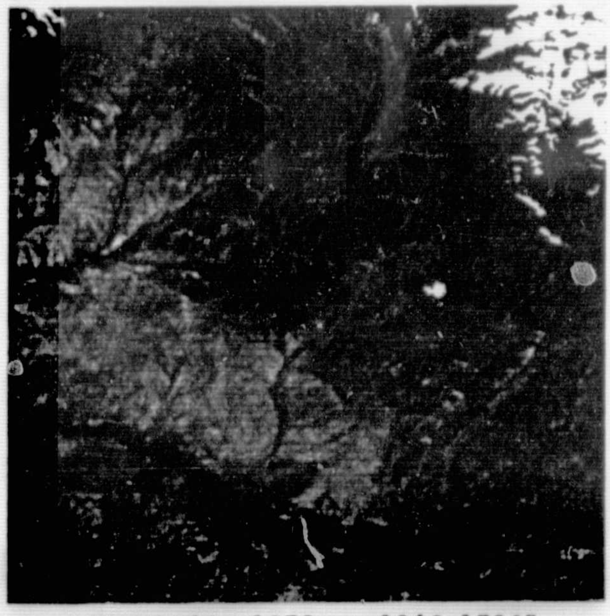


Figure 23a. Spring growing season imagery enables identification of productive grassland areas (312) within the salt desert (324). The upper image is scene 1246-17263 acquired March 26, 1973; the lower image is scene 1066-17251 acquired September 27, 1972. Grand Junction, Colorado is near the center of the lower illustration. Note also how snow patterns can confirm elevational relationships in plateau country where relative elevations are not clear from non-stereoscopic imagery. Such associated evidence often enables correct identifications of vegetation and related soil conditions.



September 27, 1972 1066-17254



March 26, 1973 1246-17265

May 19, 1973 1300-17263

Figure 23b. Three seasons of imagery help identify vegetation in mountainous regions. The top image separates oakbrush (327.1) from pinyon-juniper (341.1), but distinction between salt desert (324) and sagebrush steppe (325) is not too clear. The earliest spring greening period (lower left image) increases the contrast between the latter two types and shows where grass cover and growth is going to be highest. The peak green period at low elevations (lower right image) clearly separates the salt desert (324) from the sagebrush (325) and shows where, in the latter, grass production is highest. Productive and non-productive juniper clearing operations are vividly contrasted at X.

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OF POOR QUALITY

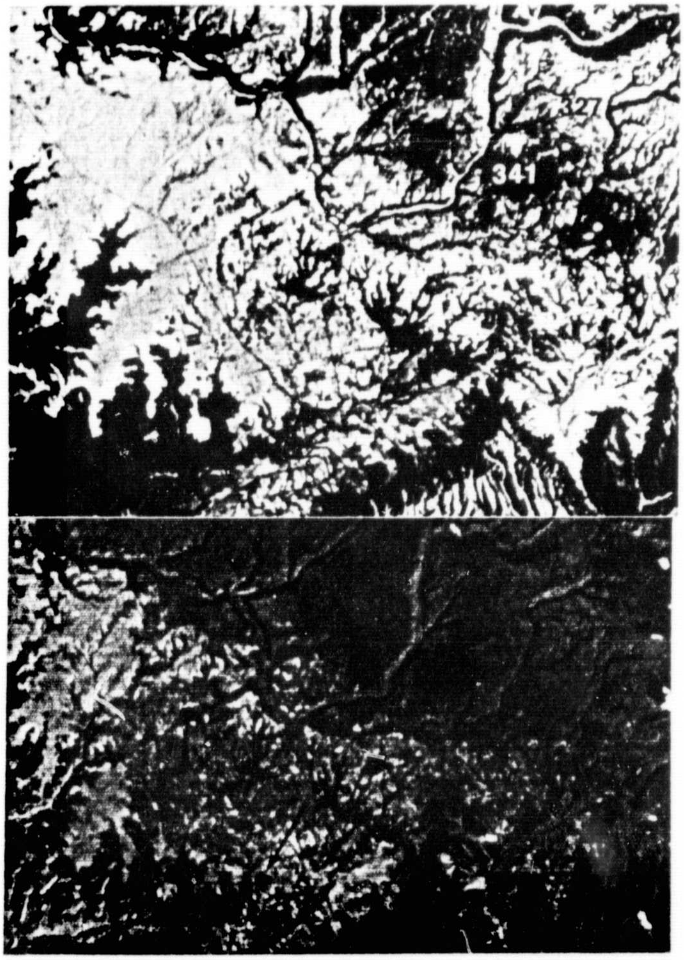

Figure 23c. Snow cover can be particularly helpful in mapping and identifying certain evergreen coniferous forests (341). The brown colors in the top image are dense stands of mature ponderosa pine (341.2). They are evidenced by a brownish cast to the image in the lower, summer photo. Note how the snow background sharpens the transition between the pine and the oakbrush (327) to the northeast. Cortez, Colorado is in the lower center of the scene (see arrow). The entire townsite is contrastingly evident in the winter scene but only the business district could be identified in the summer scene.

C-2

Likewise, aspen woodlands are more positively identified by comparison of spring and summer imagery with imagery taken both before and after leaf fall. In addition, if imagery is available at the proper seasons, one can often differentiate Gambel's oak from aspen because of differential timing of leaf development and leaf fall.

13.0 VEGETATION ANALOG MAPPING COMPARISONS

Vegetation mapping from ERTS-1 imagery and subsequent comparisons with recent, independently prepared resource maps have been completed in both test areas. In the Sierra-Lahontan Test Area comparison was made with map No. M7-S-2256-N from a joint federal/state study conducted by the Nevada Department of Conservation and Natural Resources, the Resources Agency of California, the U.S. Forest Service, and the Soil Conservation Service. In the Colorado Plateau Test Area comparison was made with "Map Atlas, Soil and Range Inventory of the Ute Mountain Indian Reservation, Colorado and New Mexico," compiled by the U.S. Bureau of Indian Affairs in 1965.

Table 11 shows the results of ERTS mapping on a 1:250,000 color reconstituted print of frame #1290-18121, 9 May 1973, from the Sierra-Lahontan test site. Table 12 shows the results of ERTS mapping on a similar color enlargement of frame #1300-17263, 19 May 1973, from the Colorado Plateau test site. The aforementioned agency maps were used as ground truth and generalized to derive mapping units that compare well with the vegetation and resource analog classes used in our ERTS interpretation. We attempted to interpret and map the ERTS imagery at the same intensity as the agency maps. In almost every case, however, it would have been possible to have done a slightly more intensive mapping job on ERTS. The study involved tabulating and comparing acreages of analogs derived from the two approaches. Acreage errors were calculated on the basis of the total project area. This gives a better picture of the consequences of ERTS interpretation and mapping errors. The comparison

Table 11. Results of Mapping and Type Identification Comparisons for Vegetation-Environment Analogs in the Sierra-Lahontan Test Site

Legend Symbol	Resource Type Description (1)	Carson River Subbasin Map Acres (2)	Carson River Subbasin Map Percent of Total (3)	ERTS Map Acres (4)	ERTS Map Percent of Total (5)	Col. (2) minus Col. (4) Acreage (6)	Discrepancy in Percent of Total (7)
110	Playas	1,614	.16	2,193	.22	-579	0.06
210	Ponds, lakes & reservoirs	7,263	.72	7,974	.80	-711	0.72
324	Saltdesert Shrublands	168,663	16.72	200,456	20.26	-31,793	3.15
325.1	Sagebrush Shrublands	318,765	31.60	282,393	28.54	+36,372	3.61
341	Coniferous Forests (*Pinus*, *Tsuga*, etc.)	263,082	26.08	265,149	26.80	-2,067	0.20
341.1	Pinyon-juniper Woodlands	126,699	12.56	156,277	15.80	-29,578	2.93
500	Undifferentiated Agriculture	116,208	11.52	73,673	7.46	-42,535	4.22
600	Undifferentiated Urban	6,456	.64	1,196	.12	+5,260	0.52
	TOTALS	1,008,750	100.00	989,311	100.00	+19,439	1.93

Table 12. Results of Mapping and Type Identification Comparisons for Vegetation-Environment Analogs in the Colorado Plateau Test Area.

Legend Symbol	Resource Type	BIA[1] Map Acres	BIA[1] Map Percent of Total	ERTS Map Acres	ERTS Map Percent of Total	B.I.A. Acres minus ERTS-determined Acreage	Discrepancy in Percent of Total
324.32	*Atriplex* and annual grasslands (sandy-loamy soils)	90,366	16.08	104,864	18.60	-14,498	2.58
324.31	*Atriplex* uplands (saline-clay soils)	65,179	11.60	64,693	11.46	+ 486	0.09
130	Rocky cliffs, non-range	58,584	10.42	31,607	5.61	+26,977	4.80
325.1	Sagebrush (*Artemisia*) shrubland	54,475	9.69	61,268	10.87	- 6,793	1.21
341.11	Pinyon-juniper Woodlands	221,238	39.37	212,530	37.70	+ 8,708	1.55
341.12	Pinyon-juniper/Oakbrush Woodlands	58,497	10.41	70,921	12.58	-12,424	2.21
327.1	Oakbrush (*Quercus gambelii*)	13,027	2.32	17,516	3.11	- 4,489	0.80
341.4	Spruce-fir (*Picea*-*Abies*) Forest	601	0.11	389	0.07	+ 2	0.04
	TOTALS	561,967	100.00	563,788	100.00	- 1,821	0.32

[1] BIA = Bureau of Indian Affairs

admittedly results in a more favorable picture than would be realized by comparing acreage of individual legend classes.

In the current comparison, relatively large errors in vegetation-environment units of small areal extent contribute minimally to the overall classification error for the project area. Thus, for both test sites the average acreage agreement was 98 percent. In some cases of poor individual agreement, the ERTS estimate is no doubt the best, and in other cases the ERTS estimates are inferior to the agency survey determinations. In other cases the disparity between the ERTS and agency survey data reflects differences in the way the resource subjects were identified by the agency teams and by our investigators; i.e., differences in legend. This matter is obviously subject to some professional judgment and complete conformity cannot be expected when separate resource inventories are done by different groups for different purposes. Considering these inherent problems of comparability, the results do place ERTS mapping in a very favorable light when the whole project area is considered.

In the results shown in Table 11, the following three vegetation and resource analogs were particularly well inventoried from the ERTS imagery: coniferous forests; ponds, lakes and reservoirs; and sagebrush shrublands. Salt desert shrublands were in a close fourth place on the basis of a type comparison. For these types the acreage errors were 0.8, 9.8, 11.4, and 18.8 percent, respectively. The disparity between maps for playa acreage determination was 35.9 percent but, because of the small total acreage of playas, they contributed only 0.06 percent to the total acreage discrepancy. Because of the clarity with which playas are shown,

however, it is highly probable that the higher estimate from the ERTS determination is the most accurate. If we assume that the agency survey accurately recorded all ponds, lakes and reservoirs, one would expect that some of the 711-acre error from ERTS represents small ponds below the resolution limit of the photographic ERTS enlargements (1:250,000). In most of these instances the resource types contrast sharply with the playas and, as a result, boundaries are readily apparent on the ERTS imagery. In addition, these water features have a color signature that is recognizable with high consistency. On the other hand, some of the overestimate on ERTS of 711 acres may represent commission errors where certain rock types or shadowed areas may have been interpreted as lakes. Furthermore, it is also possible that some of this error could reflect variations in water level between the dates of the two separate inventories. Because of the distinctness of this signature, however, it is highly probable that the ERTS determination is closer to the true 1973 record.

The overrepresentation of salt desert and pinyon-juniper woodland, and the underrepresentation of sagebrush, agriculture, and urban areas on the ERTS mapping, can be partially explained by differences in boundary interpretation between the two independent studies. The agriculture and urban classes are both underrepresented on the ERTS mapping because extensive areas, mapped in the joint federal/state study as agriculture or urban areas, are actually covered by big sagebrush. In the ERTS interpretation they were so classified. This leaves unexplained the "underestimate"

of sagebrush land by ERTS interpretation. This net result probably represents some commission and omission errors in ERTS interpretation even though we feel that the sagebrush analog does have a reasonably good color signature in this region. Added to this are a host of other causes of disparity that balanced out to produce differences between the two surveys. The following exemplifies some of the probable causes of disparity.

A careful analysis of the agency maps revealed that privately owned sagebrush lands used for natural pastures or areas that included some abandoned croplands grown back to rabbitbrush and sagebrush tended to be classified as agriculture. This resulted in a high estimate of agricultural land and a depression of the sagebrush shrubland acreages in the federal/state study. In the ERTS interpretation, these private land acres are indistinguishable from the sagebrush analog thus resulting in a lower and possibly even more accurate ERTS estimate of agricultural crop land. In addition, the possibility of actual changes in crop land acreage between the two studies has not been confirmed as a possible factor in the disparity.

The disparity in urban class acreage probably has two causes: (1) we were unable, from the ERTS, to distinguish all of the small urban areas and; (2) there is a disparity in the way urban area was determined in the two studies. The ERTS interpretation allocated to urban only those lands that the image clearly showed to be dominantly urbanized. It is readily apparent from careful study of the agency map that some sagebrush and rabbitbrush on private lands adjacent to or intermixed with suburban development tended to be classified urban in the agency study while scattered urban development could not be detected on the ERTS images.

The difference between the sagebrush and pinyon-juniper woodland types on the ERTS map versus the agency map is largely due to the difference in the way the two groups of workers interpreted savanna and woodland. The agency group classified vegetation on the basis of dominant species. Thus, a savanna-like pinyon-juniper woodland would have been classed in many instances with the sagebrush analog because sagebrush is the dominant in terms of biomass. In the ERTS classification it was possible to discern both the dense and many of the savanna-like stands of pinyon-juniper. The latter were classed with the pinyon-juniper analog in ERTS interpretation regardless of the sagebrush understory. In spite of the 23 percent disparity between the two estimates of pinyon-juniper woodlands, this vegetation analog does have a recognizable color signature; we are finding that it can generally be distinguished from its two most common neighboring zones--namely, ponderosa pine above and sagebrush below. Thus, we have high confidence in most of our pinyon-juniper identifications. The main problems arise where pinyon-juniper grades from a savanna-like ecotone with the sagebrush and intermixes to some degree with the drier ponderosa pine sites at the upper elevation ecotone. Such gradients are always subject to a somewhat arbitrary delineation decision by the image interpreter.

For the Sierra-Lahontan test site comparison, the average disagreement between the ERTS and agency maps on a type-by-type basis was 27.4 percent. When this was converted to its total project area consequence, by considering both individual error and acreage in proportion to total, the average discrepancy as a percent of total area reduced to 1.9 percent.

Table 12 summarizes similar comparative mapping on the Colorado Plateau between our ERTS interpretations and inventories prepared by the Bureau of Indian Affairs for an identical 562,000 acre area. This area includes some of the same analogs as well as some new ones. On the basis of individual type comparisons, outstandingly good agreement was achieved for pinyon-juniper woodlands and salt desert or Atriplex uplands on saline, clay soils. Discrepancies were 3.9 and 0.7 percent, respectively. Good agreement was achieved for sagebrush shrublands and for salt desert or Atriplex-annual grasslands on sandy to loamy soils, 12.5 and 16.0 percent discrepancy, respectively. While dense pinyon-juniper woodlands were exceptionally well mapped (3.9 percent discrepancy), pinyon-juniper mixed with Gambel oak was less well identified (21.2 percent discrepancy). On an individual type comparison basis, poorest agreement was achieved for rocklands (46.0 percent discrepancy) and for spruce-fir forest, a very minor component with 35.3 percent discrepency between the two surveys. In this part of the Colorado Plateau Test Area, the spruce-fir forest occurred almost exclusively on north slopes at higher elevations. They generally were in juxtaposition with oakbrush communities. By carefully comparing the ERTS image with the agency map, we felt that we were able more accurately to discern the portions of these north slope environments that were spruce-fir vegetation. Because of the samll patch distribution of Douglas-fir and the prominence of oakbrush, the other conifers were allocated as inclusions to the oakbrush type, thus partially accounting for both our underestimate of spruce-fir and over-estimate of the oakbrush type.

Similarly, our disparity in rockland or non-range mapping can largely be explained on the basis of a different mapping philosophy. The agency map included as rocky cliffs and non-range many steep areas that were significantly vegetated, whereas our attempt was to define the truly rockland, non-vegetated areas. In all other cases we felt that we were conceptually mapping the same analogs in the two studies. The comparison, therefore, would be expected to differ in the former case, and to be in reasonably close agreement in the latter.

Similarly, on the basis of total area and considering both total type acreage and the discrepancy in individual type identification, the weighted average acreage error reduced to 0.32 percent over the whole project.

In spite of the wide disparities in identification and mapping of some individual types and considering that acreage comparisons were made on enlarged bulk data products, these comparisons are highly encouraging. They suggest that one can make highly accurate regional vegetation maps at a scale of 1:250,000 by direct interpretation from good-quality ERTS color products.

Obviously, this level of identification by human interpreters from ERTS "photographic products" cannot be achieved in an information vacuum where the interpreter does not know what to expect on the landscape being examined. He obviously must know the ecology of the landscape and draw heavily on convergent and associated evidence in reaching his identification decisions. In both of these comparisons we were particularly encouraged to learn that we could do so well in identifications at the fourth level in our legend system. Four analogs were identified at the

fifth level (Table 12). Using this kind of stratification as a starting point, multistage sampling with appropriate scales of aircraft data should enable highly accurate determination of acreage and quality parameters of vegetation analogs in regional surveys at county, state and national level.

14.0 IMAGE QUANTIFICATION BY TRANSMITTANCE VALUES AND RATIOS

Intra- and interregional analyses of vegetation-environmental analog transmittance characteristics were conducted using an electronic image analysis system available at the EarthSat, Berkeley facility.

Black-and-white 9"x9" positive transparencies of Bands 5 and 7 were analyzed for five ERTS frames. Two ERTS frames were used in the Colorado Plateau Test Area (#1372-17252, 30 July 1973 and #1372-17254, 30 July 1973). Three frames were analyzed in the Sierra-Lahontan Test Area (#1379-18052, 6 August 1973; #1380-18111, 7 August 1973; and #1381-18163, 8 August 1973).

Thirty-five macroplots of irregular size and shape were outlined on each positive transparency. Each macroplot represented one analog type and thus was homogeneous as to its photographic image features. A variable number of sample plots were identified by coordinates on the electronic image analyzer within each of these macroplots. The number of sample plots within each macroplot varied from four to twelve depending upon the shape and size of each macroplot. The equivalent ground size of each sample plot at which transmittance values were read was approximately 138 feet square (0.44 acres).

Table 13 shows the relative transmittance values determined for each of four analogs on Bands 5 and 7. This table shows the means and standard errors of the observations. On critical examination some of the data showed considerable variation and consistent density difference was apparent in all the images between the two regions. The aspen, riparian cottonwood, and

Table 13. Transmittance Values Band 5 and 7 Read from Black-and-White Photo Transparencies

Analog Type	Legend Symbol	ERTS Frame	Test Area	Transmittance Value ± Standard Error: Band 7	Transmittance Value ± Standard Error: Band 5	Number of Samples
Riparian Cottonwood (*Populus*) Communities	342.3	1372-17252	Colorado Plateau	560.9 ± 3.0	368.8 ± 5.0	39
	342.3	1379-18052	Sierra-Lahontan	489.4 ± 13.8	304.1 ± 2.6	15
Aspen (*Populus tremuloides*) Communities	342.4	1372-17254	Colorado Plateau	773.8 ± 18.0	172.1 ± 2.8	50
	342.4	1380-18111	Sierra-Lahontan	500.4 ± 10.6	131.7 ± 3.2	15
Pinyon-Juniper (*Pinus monophylla-Juniperus osteosperma*) Woodland	341.1	1372-12254	Colorado Plateau	526.3 ± 6.9	402.1 ± 3.6	50
	341.1	1372-12254	Colorado Plateau	486.7 ± 4.8	361.2 ± 4.0	40
Sedge (*Carex*) Meadow Communities	315.1	1372-12254	Colorado Plateau	890.6 ± 14.3	242.9 ± 5.6	45
	315.1	1381-18163	Sierra-Lahontan	362.8 ± 10.2	77.8 ± 1.2	20

sedge meadow seemed to be uniquely separable from one another and the pinyon-juniper was separable from aspen and sedge meadow but doubtfully from the riparian cottonwood. The Band 5 and 7 transmittance values did maintain the same relative relationship within each vegetation type between the two regions. For these reasons it was thought that band ratioing might compensate for some of the difference in film density and show more similarity both between regions and within vegetation type. Band ratios were accordingly calculated as follows:

$$\frac{\text{Band 7} - \text{Band 5}}{\text{Band 7} + \text{Band 5}}$$

Table 14 summarizes the ratios and their standard errors.

Ninety sample plots of the pinyon-juniper analog were analyzed on two frames covering different areas within the Colorado Plateau Test Area. The La Salle Mountains-Uncompaghre Plateau area of Utah and Colorado provided 40 sample plots and the Four Corners-Mesa Verde area provided 50 sample plots of this analog. All macroplots were located between 6,800 and 7,600 feet elevation (113 to 127 days after snowmelt) so phenological development is estimated to have progressed to nearly identical stages. Ratio values for this dense pinyon-juniper vegetation with an oakbrush (Quercus gambelii) understory are nearly identical. Even though the image on frame #1372-12254 is less dense than the image on #1372-12252, the ratio of densities from Bands 7 and 5 for the pinyon-juniper analog are similar, 13.5 $\pm$ 0.45 and 15.3 $\pm$ 0.46, respectively. The next closest ratios compared were for the riparian cottonwood communities (Table 14).

Table 14. Band 5 & 7 Ratios Improve Discrimination of Vegetation Analogs

Analog Type	Legend Symbol	ERTS Frame	Test Area	Mean Values $\pm$ Standard Error of: $\left(\frac{\text{Band 7 - Band 5}}{\text{Band 7 + Band 5}} \times 100\right)$	Number of Samples
Riparian Cottonwood (*Populus*) Communities	342.3	1372-17252	Colorado Plateau	20.2 $\pm$ 0.50	39
	342.3	1379-18052	Sierra-Lahontan	22.9 $\pm$ 1.02	15
Aspen (*Populus tremuloides*) Communities	342.4	1372-17254	Colorado Plateau	63.3 $\pm$ 0.45	50
	342.4	1380-18111	Sierra-Lahontan	58.2 $\pm$ 0.36	15
Pinyon-Juniper Woodland	341.1	1372-12254	Colorado Plateau	13.5 $\pm$ 0.45	50
	341.1	1372-12252	Colorado Plateau	15.3 $\pm$ 0.46	40
Sedge (*Carex*) Meadow Communities	315.1	1372-12254	Colorado Plateau	56.9 $\pm$ 0.97	45
	315.1	1381-18163	Sierra-Lahontan	64.5 $\pm$ 0.74	20

Three interregional analogs were analyzed for their transmittance characteristics in Bands 5 and 7. Sample plots of riparian cottonwood analogs are characterized by relatively similar transmittance values (Table 13) in both test areas. The Sierra-Lahontan image is relatively more dense than the Colorado Plateau image. The ratioed values (Table 14 and Figure 24) are closely alike indicating a high interregional similarity of ERTS image characteristics for this vegetation-environmental analog.

Since the riparian cottonwood analog sample plots are located at about 4,200 feet elevation in both study areas, time after snowmelt cannot be used to evaluate phenological conditions for this vegetation analog. However, most cottonwood stands along permanent streams in western North America are phreatophytic and follow generally similar growth and development patterns. The variability between transmittance ratio characteristics cannot be attributed to any one major factor or complex of factors. Some of the small interregional difference may be due to phenological stage of development between the two regions.

Figure 24 shows the same transmittance data expressed as a band ratio. The bars in this figure show $\pm$ one standard deviation around the mean. The following tentative conclusions are suggested by these tabular and graphic portrayals of the data:

1. The raw transmittance values do suggest interregional similarity when variations in film density are accounted for and phenological stages are closely similar.

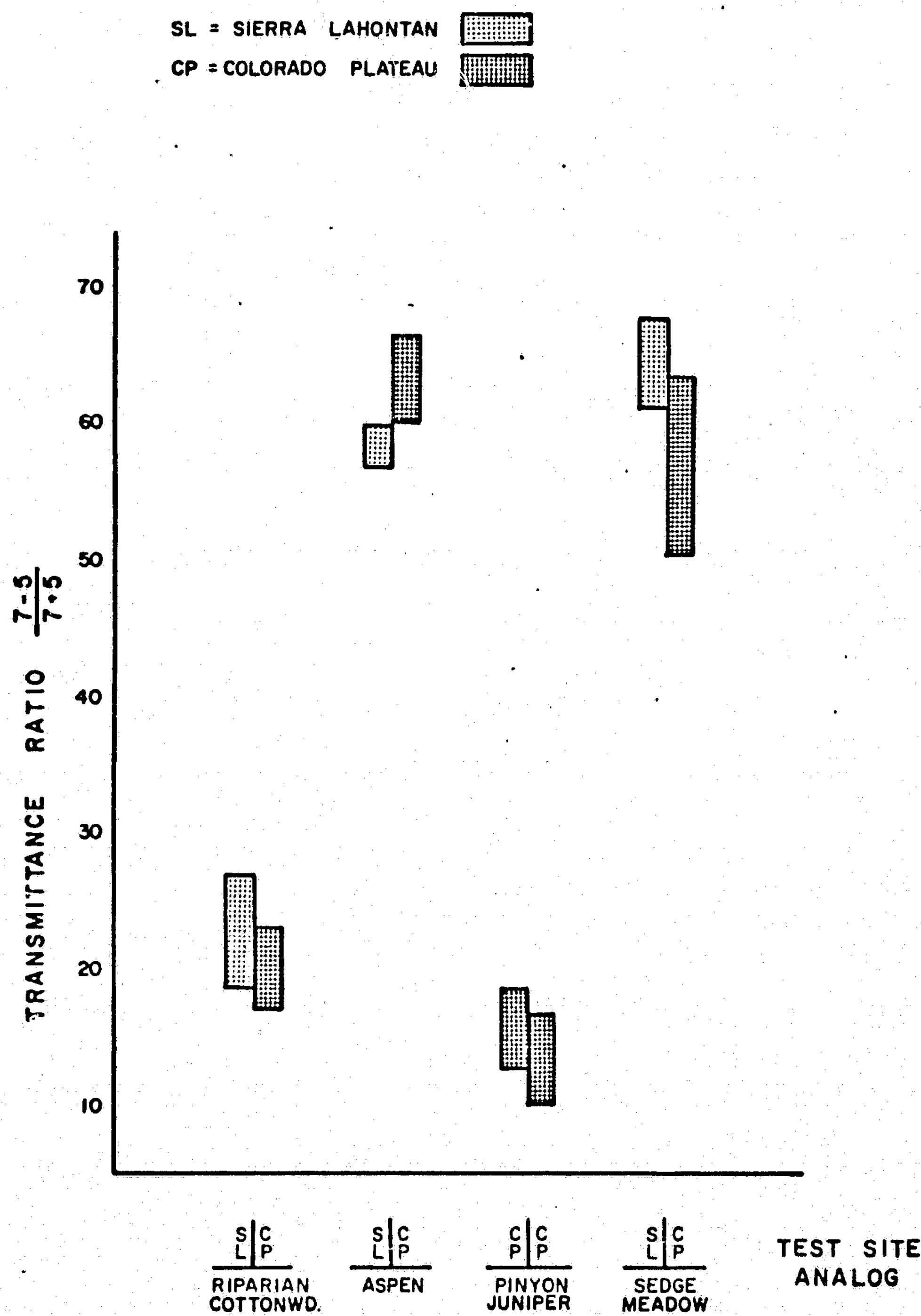

Figure 24. Transmittance ratio values for Bands 5 and 7 of vegetation analogs from ERTS imagery.

2. The relatively higher variability of Band 7 transmittance for aspen in the Colorado Plateau Test Area may be due in part to the clonal difference in phenology that is typical of this species. This variability is evident within otherwise uniform stands, particularly in spring and fall. It is possible that the resolution of the ERTS system and of our transmittance measurements detected this clonal variability. Genetically all aspen plants within any given clone are identical and, therefore, phenological development varies clone by clone.

3. On the basis of individual transmittance values, it does not appear that pinyon-juniper is readily separable from the riparian cottonwood analog, but Figure 24 suggests that they may be separable on the basis of the Band 5:7 ratio.

4. The intraregional pinyon-juniper transmittance ratios (on successive frames in the same orbit) are not significantly different.

5. Band ratioing greatly improves the interregional comparability of analog signatures, strongly suggesting the value of additional comparative studies to characterize interregional analogs on the basis of band ratios. This should be especially successful if determined from the digital tapes.

6. The band ratio signatures for aspen and sedge meadow analogs are, as a set, strongly differentiated from the riparian cottonwood and pinyon-juniper analogs, as a second set.

7. Individual members of each of these two sets do not appear separable by the ratios used in this experiment. Sedge meadow and aspen appear separable in the Sierra-Lahontan test site, but the separability of ratio signatures for these two analogs is in doubt in the Colorado Plateau test site. This is partially due to the persistent high variability of the sedge meadow ratios for the Colorado test site.

8. In contrast to the sedge meadow situation, it is interesting that the ratioing technique reduced the extremely high variability of the aspen signature in the Colorado Plateau test site.

15.0 RICE ANALOG STUDY

15.1 PROBLEM

15.1.1 INVESTIGATE THE USEFULNESS OF ERTS-1 IMAGERY AND ASSOCIATED AIRCRAFT PHOTOGRAPHY FOR MONITORING RICE CROPS IN CALIFORNIA AND LOUISIANA

15.1.2 DEVISE A METHOD OF CROP PRODUCTION ESTIMATION USING MULTISTAGE ANALYSIS TECHNIQUES

15.2 APPROACH

15.2.1 COLLECT ERTS-1 DATA FROM THE MULTISPECTRAL SCANNER (MSS) AT SPECIFIED TIMES DURING THE CROP GROWING SEASON

A standing order was submitted for return beam vidicon (RBV) and MSS data at each overpass for the following periods:

Location	Period
Northern Great Valley Rice Test Area	1 March 1973 through 30 September 1973
Louisiana Coastal Plain Rice Test Area	15 February 1973 through 15 September 1973

Because of the July 1972 ERTS-1 launch data and because the rice growing season starts with planting in March in Louisiana and April in California, we could not begin our detailed crop studies until the

1973 growing season. By requesting ERTS-1 coverage at each 18-day overpass, we would have a better chance of getting images when favorable weather conditions prevailed over the study area even though coverage was needed only at certain critical dates during the crop growth. (As explained in a later section, good cloud-free coverage was obtained of the California rice study area and no cloud-free coverage was obtained of the Louisiana rice study area during the growing season.)

15.2.2 TAKE AERIAL PHOTOS AND COLLECT GROUND TRUTH DATA AT SPECIFIED LOCATIONS AND TIMES IN THE RICE GROWING AREAS

In order to employ multistage sampling techniques, whereby images are obtained of large areas at small scales and progressively smaller areas at larger scales, it was necessary to take aerial photos at each scheduled ERTS-1 overpass date from several altitudes. We utilized photos taken by NASA high-flight aircraft (U-2 and RB-57) for the medium-scale coverage (1:65,000). Project staff used a rented aircraft to take large-scale aerial photos and to perform observation flights for crop identification, classifying growth problems (soil deficiencies, weed infestation, gaps in plant cover) and determining crop status in the growth cycle (or emergence, heading, and ripening).

Test locations were selected for detailed study and where cooperating farmers and experiment station personnel could assist in crop identification and analysis.

Aerial photos and data from aerial observation of the detailed test locations were used in establishing ground truth and for determining the interpretability of ERTS-1 images for detecting the crop features of interest.

15.2.3 PERFORM PHOTO INTERPRETATION OF ERTS-1 AND AIRCRAFT PHOTOS AND EVALUATE THE CONTRIBUTION EACH INPUT MAKES TO CROP MONITORING

For each of the detailed test sites where aerial photos were obtained and where ground and aerial observation provided ground truth, images were evaluated at the various multiple stages (ERTS-1, high-flight, and low-altitude photos) to determine the contribution each made and thus define the levels of scales needed for operational crop analysis.

These interpretations were made in a systematic manner by project staff working first with the aerial photos (which were available within a few days after a mission) then with NASA high-flight and ERTS-1 data (which were available six to eight weeks after being taken).

At each level of scale, from ERTS-1 through high-flight to low-altitude aerial photos, image interpretation determined what information could be detected consistently of the type needed for crop analysis (crop status, crop identity, growth problems, pest, and weed damage, vigor, and stress indicators).

15.2.4 CONDUCT PHOTO INTERPRETATION TESTS OF SELECTED AREAS AND PHOTO INPUTS TO DERIVE QUANTITATIVE AND QUALITATIVE IMAGE EVALUATION DATA

During the course of the investigation, ERTS-1 and Skylab photographs and ground data were assembled for use in conducting photo interpretation tests that would quantify the usefulness of various images for crop monitoring.

These images were prepared by drafting overlays marking the fields to be identified as to crop type. Subsequent tests were made to determine the interpretability for such questions as crop status, vigor, and minimum field size identifiable on the images.

The responses of the test interpreters were scored and the number of correct responses and the types of errors made were tabulated. From this procedure it was possible to rate the usefulness of the various image types and dates of coverage for the purposes cited.

15.3 SCOPE

15.3.1 STUDY SITE SELECTION PROCEDURE FOR CALIFORNIA AND LOUISIANA

The criteria for choosing the sites for the primary sample units (PSUs) were the presence of a high density of rice cultivation and typical cultural practices. The cultural practice characteristics considered were: the field sizes, the probability of disease occurrence, the availability of organized assistance such as county farm advisors, university facilities, etc., or previous experience from studies done in the areas. In choosing the basic study areas it was recognized that there was a high probability of weather interference in the Louisiana test site compared to the California test site.

The two basic study areas chosen were the Northern Great Valley of California and the South Central Louisiana Coastal Plain. The Louisiana area was chosen on the basis of its extensive rice cultivation and the high incidence of various diseases, thereby providing an excellent area for testing the yield estimation method developed by Welch (1965).[1] However,

[1] Project ACRE, U.S. Government (Classified); 1965.

weather in Louisiana is a problem where aerial surveillance is being used. For this reason, and to include rice culture variability, the Northern Great Valley of California was chosen as an additional test site. The more arid climate made image acquisition more likely, but disease incidence is not as high. The location of these test areas can be seen in Figures 25 and 26.

In each of the basic study areas, specific study sites were defined in order to limit the areas in which ground data were to be collected. These areas were designated as subsample units (SSUs) and were selected by consideration of many criteria.

To facilitate the acquiring of large-scale aerial photography, the SSUs were generally contiguous and rectangular. The resultant SSUs were long and narrow, generally with dimensions of four miles by 10 to 15 miles. The specific location of each area took into account several factors. To facilitate ground data acquisition. the areas were laid out to be accessible from public roadways. The areas were also chosen to be representative of:

a. Soils

b. Microclimate or moisture regimes

c. Topography

d. Crop type mixtures

e. Cultural practices.

The SSUs can be located and compared with the basic study areas in Figures 27 and 28.

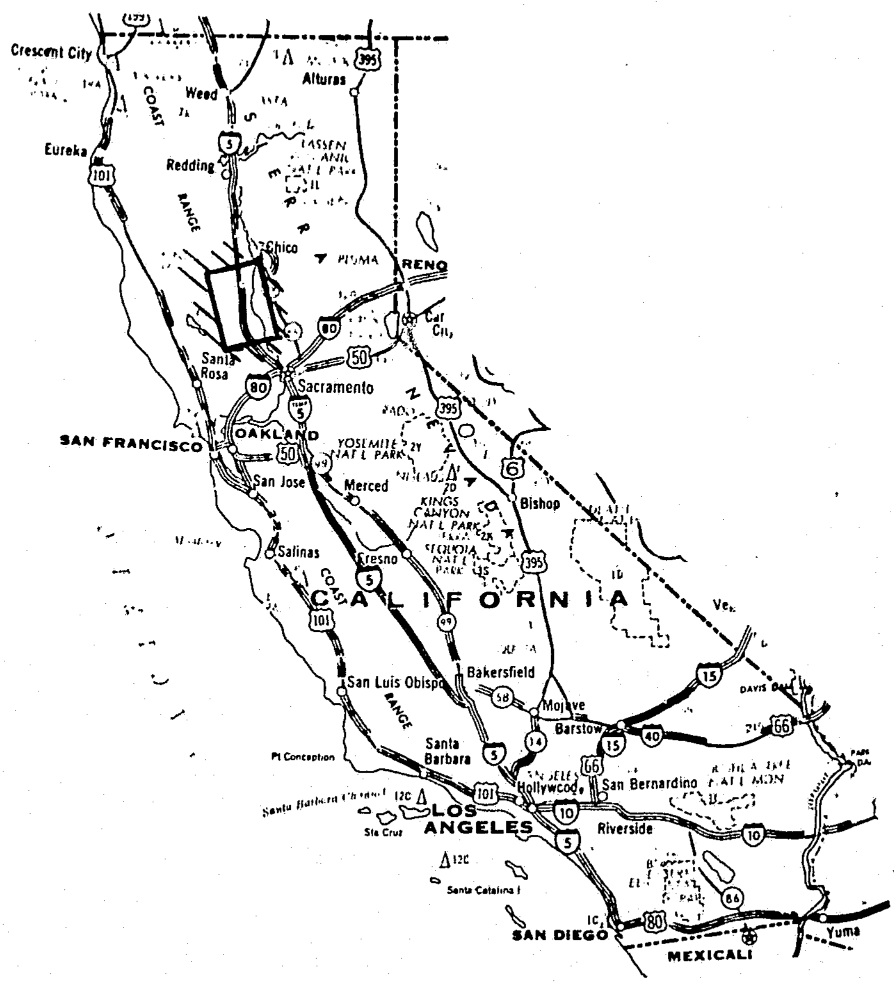

Figure 25. Northern Great Valley Test Area.

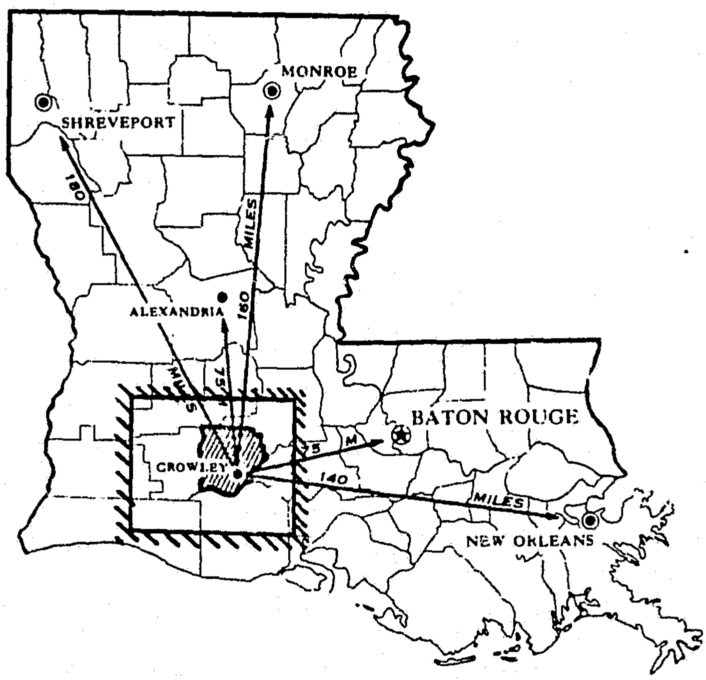

Figure 26. Louisiana Coastal Plain Test Area.

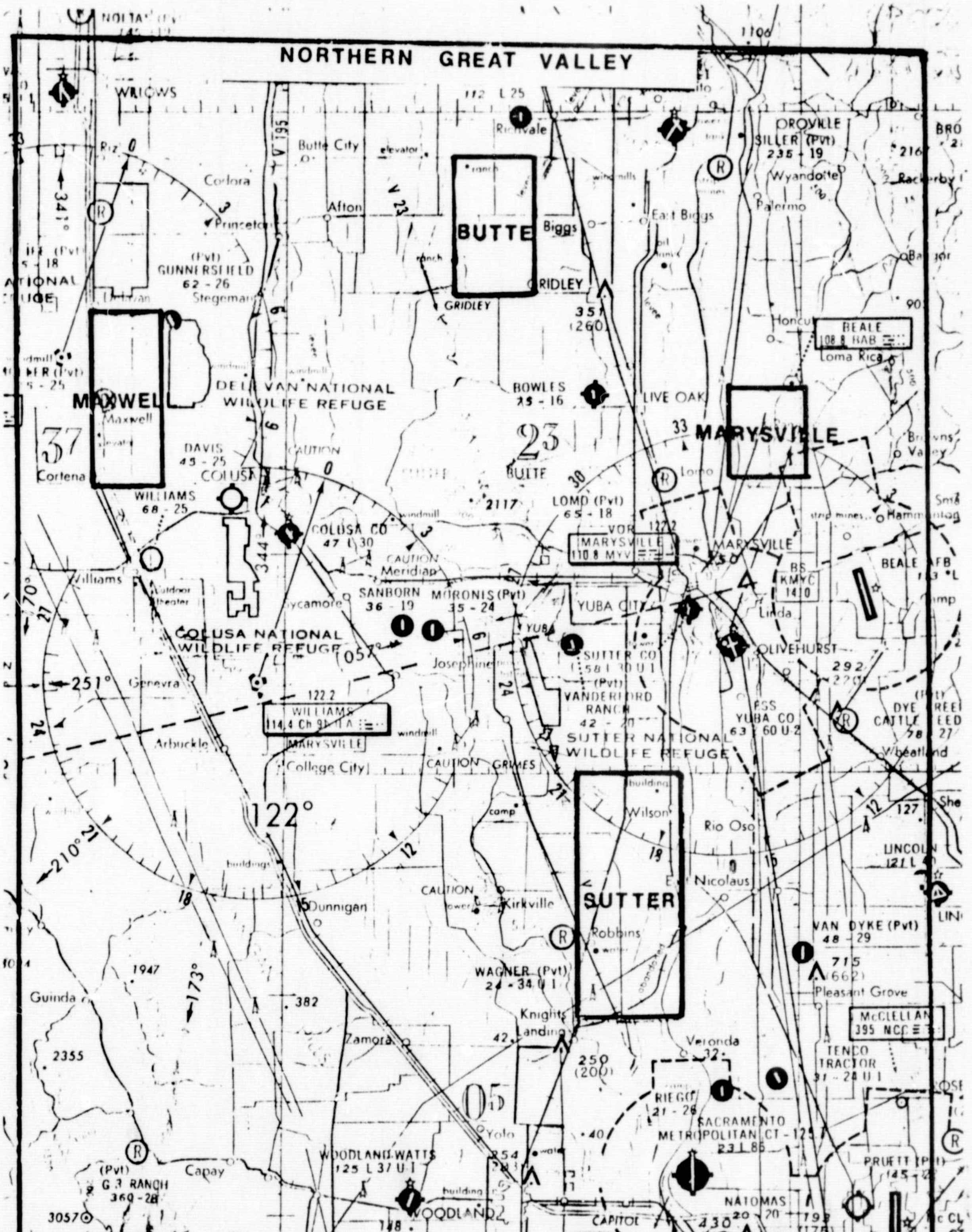

Figure 27. Primary and Secondary Sample Units, Northern Great Valley.

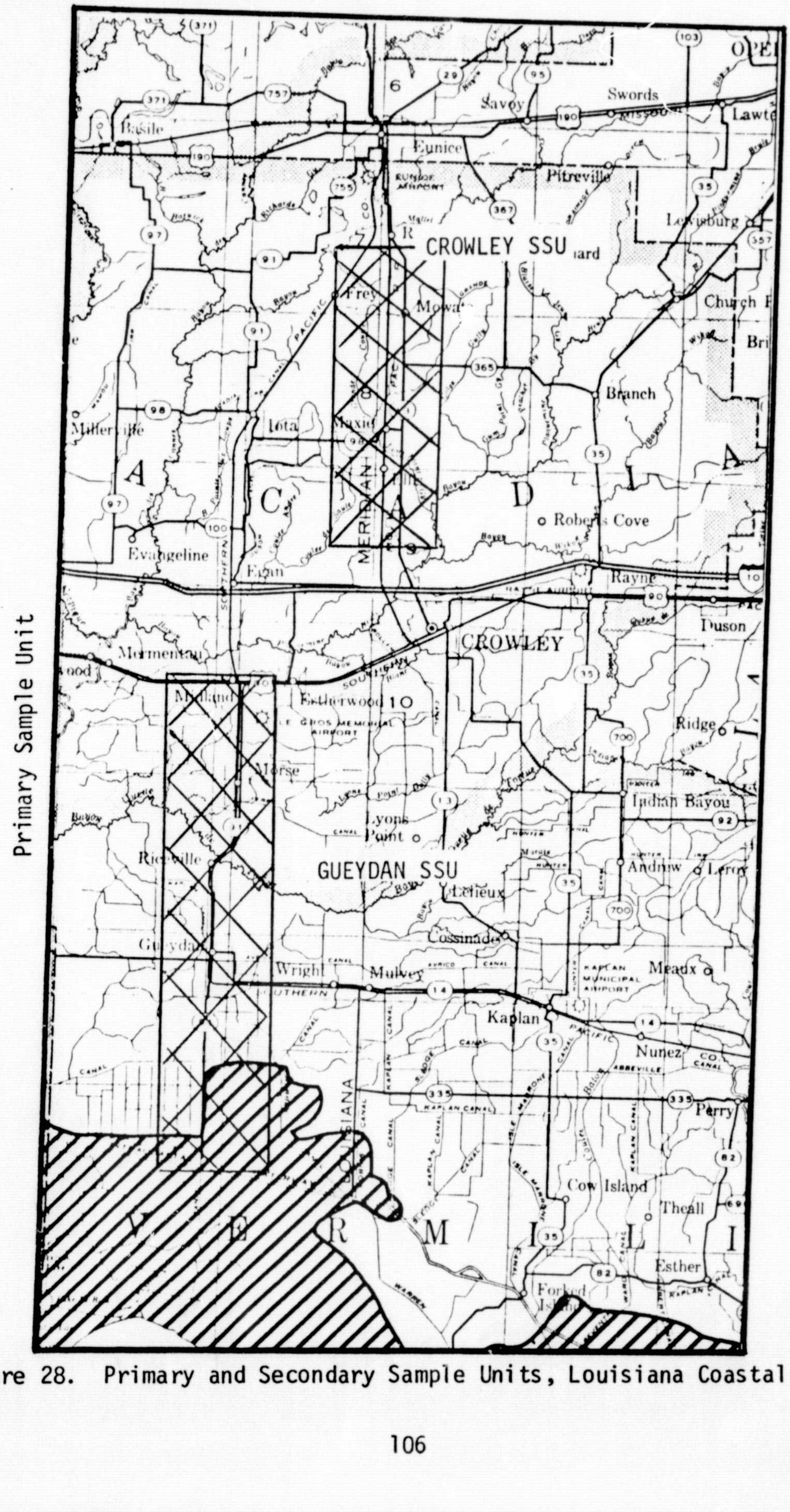

Figure 28. Primary and Secondary Sample Units, Louisiana Coastal Plain.

After establishment of the SSUs, individual farmers whose fields were in the SSUs were contacted about the possibility of providing their cultural information in order to supplement our ground data collection. The individual fields of cooperating farmers were then observed throughout the season using large-scale aerial photography and ground photography. These individual fields were to be the final stage in the multistage procedure.

15.3.2 PRIMARY SAMPLE UNIT (PSU) DESCRIPTION

15.3.2.1 Louisiana Coastal Plain

The south central Louisiana Test Area is located on the floodplains of the Mississippi River. Its climate is controlled by the proximity to the Gulf of Mexico and its latitude. The summers are warm and humid with precipitation often falling from thunderstorms. The winters are also moist; however, temperatures can dip to below freezing. Severe storms often lash the coastal regions and bring hurricane force winds which reach far into the interior regions.

The major crop types include rice, soybeans, sugar cane, corn, pasture, and cotton. Specifically for rice there are two major types, medium and long grained. The predominant varieties are Nato, Nova, Blue Bonnet, and Zenith. A majority of the rice is seeded in April and May; however, the seeding season can extend from the middle of March through the end of June depending on variety and conditions. Seeding in 1973 was delayed until the end of May by unseasonal rains which kept the ground too moist to work properly. Seeding is done by two basic

methods, grain drilling or airplane broadcast. Fertilizer application is done initially by drill or airplane and later in the season another application (top dressing) is done by airplane. Recommended application rates of nitrogen, phosphate, and potash are 40 to 80 lbs./acre, 20 to 40 lbs./acre, and 0 to 40 lbs./acre, respectively. Broadleaf and grass type weeds are a problem dependent on cultural practices. Diseases such as stem or leaf blast are a problem and can severely limit the rice yield. Insects, primarily root weevils, can also cause severe damage. Water management and soil preparation follow two basic patterns:

a. Fields are cultivated and leveled while dry and subsequently flooded, and
b. Fields are plowed and leveled while flooded.

Fields are then seeded by airplane and water is temporarily drained off when the seeds germinate to facilitate stable rooting. The fields are reflooded in two to three days and kept at about four to eight inches of water depth until harvest time. Dry leveled fields are generally worked dry and drilled, the fields are flooded to a depth of about four to six inches until the seed germinates. After germination the water is drained for about two to three days and then returned to a depth of six to eight inches for the remainder of the season. Fields are drained prior to harvest and harvesting is done with a combine when fields are dry and rice kernels have between nine and 16 percent moisture content. Average yields for the south central Louisiana area are about 32 barrels/acre (1 barrel = 113 lbs.).

15.3.2.2 Northern Great Valley Primary Test Site

The Northern Great Valley Test Area is located in the northern half of the Central Valley of California. The climate of the area is

Mediterranean to semi-continental. The winters are cool to cold with temperature ranges from 25° to 70°F. A majority of the precipitation occurs in the winter. The summers are warm and dry; temperatures range from 60° to over 100°F with some precipitation falling from sporadic thundershowers. The soils consist primarily of alluvial loamy sands. Over the entire area the crop type diversity is great, including rice, tomatoes, alfalfa, sugar beets, corn, sorghum, beans, peppers, wheat, barley, oats, safflower, orchard, vineyard, and pasture. The combination of clear, arid summer weather and the high crop diversity creates an excellent study area.

The majority of the rice is seeded by airplane into flooded fields. There are four major varities used: Caloro, SC-S4, Calrose, and CS-M3. The planting season is generally from March to May. The fields are cultivated and leveled before flooding. Fertilizer is applied during the field preparation. The rice seed is then presoaked for 24 hours to soften the seed coat and initiate germination. The presoaked seed is then sown by airplane onto the flooded fields. Top dressing of fertilizer is applied in a manner similar to Louisiana practices. The total nitrogen applied is about 100 lbs./acre. Weeds are a problem in California and include water hyacinth, bull rushes, and Johnson grass. Some root weevils are present and shrimp can be a problem. Otherwise few pests or diseases bother the California farmer. The fields are continuously flooded to a depth of six to eight inches from seeding to about two weeks prior to harvest time. The harvesting is done by combine when moisture content of the rice kernels drops to about 10 to 12 percent. The average yield for the California rice growing area is about 53 sacks/acre (1 sack = 100 lbs.).

15.3.3 INDIVIDUAL SUBSAMPLE UNIT (SSU) DESCRIPTIONS

15.3.3.1 Louisiana Coastal Plain PSU

15.3.3.1.1 Crowley SSU

This SSU is located north of Crowley, Louisiana. It is a 4-by-12-mile (48 square miles or 30,720 acres) block with its long axis oriented north-south. The soils are primarily silt or clay loams. In the northern portion are found the silt loams. These soils are deep and imperfectly drained, strongly acid to moderately alkaline. Sometimes hardpans or concretion may form at depths. The southern soils are clay loams and are found in generally lower places and are even more poorly drained. Otherwise the southern and northern soils are very similar. Rice and soybeans are the major crop types in the Crowley subsample unit. Other crops include corn, sorghum, sweet potatoes, cotton, and pasture. In the Crowley Test Area dry leveling and drill seeding is the predominant method used in soil preparation and planting.

15.3.3.1.2 Gueydan SSU

This SSU is located south and west of Crowley, Louisiana. The major town situated in the area is Gueydan, Louisiana. The area is a 4-by-19-mile unit (76 square miles or 48,640 acres) with the long axis oriented in a north-south direction. The climate is more humid than that of the Crowley SSU due to the nearness of the Gulf of Mexico and coastal marshes. The soils range from the Midland type clay loams in the north, to the mucky heavy clay loams of the marsh soils in the south. All are very poorly drained and the marsh soils are very high in organic material content.

The major crop types are rice, soybeans, and pasture. The predominant soil preparation and planting practice in this unit is the working of the fields in flooded condition and rice seed sowing by airplane into the flooded fields. All other cultural practices are essentially the same as in the Crowley area. Due to the slightly higher humidity, diseases are often more of a problem in this southern unit.

15.3.3.2 Northern Great Valley PSU

15.3.3.2.1 Sutter SSU

This site is located approximately 20 miles north and west of Sacramento, California. The test area is approximately 100 square miles in size, and contains the town of Robbins. The area is flat-lying with the major feature being the Sutter Bypass, a flood diversion channel from the Sacramento River. The parent material is recent alluvium deposited by the Sacramento and Feather Rivers. The soils consist of sandy clay loams, are deep and moderately-to-poorly drained, and are rich and well suited for all forms of agriculture. The climate is influenced slightly by the delta region. Precipitation is generally 20 to 30 inches (50 to 80 cm.)/year, mostly falling in winter as rain, with scattered thundershowers in summer. Daily temperatures range from 30° to 50°F in the winter, to 60° to 90°F during the summer. Frosts are common beginning in September and continuing through May.

The major crop types found in the Sutter area are rice, tomatoes, safflower, alfalfa, corn, sugar beets, orchards and vineyards, wheat and barley, and assorted row crops.

A brief description of each crop type and the cultural practices is as follows:

Rice. Fields are diked and flooded in March and seeded by airplane in April or May. There are four major varieties, two of which are early varieties and two late varieties. This mixture of varieties creates a complex mosaic of planting dates and phenological developments. The crop emerges from water in about four weeks and quickly forms 100 percent cover. The vegetative growth takes about two months, during which time fields are top dressed with nitrogen fertilizer by airplane. The crop heads and begins to mature 90 to 120 days after planting, depending on variety, and is harvested by combines when the grain has dried to 10 to 12 percent moisture content. Neither weeds nor disease present a serious problem.

Alfalfa. The season starts around March and runs until late October. Generally five cuttings are made in a season. After each mowing the cut alfalfa is laid in rows for drying, a week to ten days, before baling. After baling the crop is flooded and the cycle begins again. The result is a crop which fluctuates from 10 to 15 percent cover to 100 percent cover four or five times a year.

Tomatoes. Fields are seeded in rows in April or May. Plants are in double rows to facilitate the mechanical picking. The plants emerge and grow for about 60 to 90 days before flowering. Final cover approaches 90 percent. The crop is irrigated at weekly intervals. In July, August, and September the plants are mechanically plucked from the ground and the tomatoes separated, leaving the fields denuded with rows of the discarded bushes.

Safflower. Fields are planted in March and grow vegetatively until June. In July the plants flower and begin to dry. During this period the

crop changes from a dark green to bright orange-yellow rather quickly. The crop is harvested when dry.

Corn. A corn crop is planted in May and quickly attains 100 percent cover. In three to five months the crop is about 1.8 to 2.2 meters tall and is harvested by mechanically removing the entire plant and separating the ears from the stalks.

Sugar Beets. This crop is highly variable in terms of planting date and harvesting. Occasionally fields planted late will carry over during the winter and will be harvested very early in the next season. The plants are seeded and emerge as spinach-like tops. They grow vegetatively for three to five months after which the tops are chopped and strewn or removed for silage and tubers mechanically dug. These fields progress very quickly from 100 percent cover of vigorous green vegetation to bare soil.

Orchard or Vineyards. These comprise perennial crops of many types including walnuts, peaches, prunes, almonds, pears, apricots, plums and grapes. These areas are distinctive by their consistent cover and pattern.

Cereal Grains. In this area wheat, barley, and oats are planted from October through December. Seeds germinate in the fall and over winter. Some late season varieties are planted in the early spring rather than the previous fall. The grains head and mature in May and June and are generally harvested in late June and July.

Assorted Row Crops. These crops include beans, melons, bell peppers, onions, and potatoes. The crop phenologies are dependent on each crop type but they all are generally planted in about March or April and are harvested by August.

In addition to the intensive types of agriculture, there are also present more extensive forms such as irrigated and non-irrigated pasture. These areas support cattle and sheep for the production of milk, meat, wool, and hides. The appearance of the irrigated pasture is dependent on the irrigation cycles and the type of forage present. The development of non-irrigated rangelands is associated with annual weather patterns.

15.3.3.2.2 Marysville SSU

The Marysville test site is located on the east side of the Sacramento Valley about five miles north and east of Marysville-Yuba City. It also contains a 100-square-mile block. This unit is located a little higher on the alluvial terrace and the soil types consist of coarser sandy loams than found in the Sutter area. These soils are moderately-to-well drained and are excellent agricultural soils. The climate is slightly more extreme than the Sutter area due to the more continental location. Rainfall is a little greater and temperature fluctuations are more pronounced.

The major crop types are rice, orchards, and extensive rangeland, with some alfalfa in the southeastern portion of the block. These crop types occupy fairly homogeneous blocks within the test site, corresponding roughly to distance from and elevation above the river bottom area. The orchards are found in the river bottom occupying the western third of the block. Rice occupies a large block of land in the middle of the test site. The eastern portion, actually merging into the foothills of the Sierra Nevada Mountains, contains the extensive natural rangeland. Crop phenologies are essentially the same as in the Sutter area.

15.3.3.2.3 Maxwell SSU

This SSU is located on the west side of the Sacramento Valley just east of the Butte sink area of the Sacramento River. The soils are moderately-to-poorly drained heavy clay loams. Some low-lying soil areas in the SSU are saline. The agriculture in the area is primarily rice. Numerous varieties are planted and some wild varieties are used. Other crops are tomatoes, milo and sugar beets in the lower portions of the SSU, and cereal grains in the foothill terraces in the western portion. Cultural practices are consistent with those in other parts of the Northern Great Valley test site.

15.3.3.2.4 Butte SSU

Located in the northern portion of the Great Valley, this SSU is near the northern extent of the rice growing areas in California. The soils in the SSU are generally lighter and better drained than in the other SSUs. Temperatures are more extreme as well, being colder in the winter and hotter in the summer, due primarily to its more continental position. Rice culture predominates in this area as well. Other crops include cereal grains, tomatoes, and safflower, but they are of minor importance during the rice growing season. Cultural practices are consistent with other Northern Great Valley rice growing areas.

15.3.4 GROUND DATA COLLECTION PROCEDURES

15.3.4.1 Large-Scale Aerial Photography

Throughout the season large-scale aerial photography was acquired by EarthSat personnel. The aircraft used was a Cessna 206 equipped for high-altitude (up to 30,000 feet) operation and multiband photography. The

purpose of this large-scale photography was to monitor selected individual fields on a high-resolution basis and to cover an entire SSU at a lower resolution, smaller scale.

Two formats were used. The high-resolution imagery at an approximate scale of 1:1,000 was acquired using a K-17 9x9-inch camera equipped with a 30.48mm (12-inch) focal length lens. For the complete SSU coverage at smaller scales, (1:20,000) Hasselblad 70mm cameras equipped with 80mm focal length lenses were used. Two emulsions, Ektachrome MS (2448) (conventional color) and Infrared Ektachrome (2443) (color infrared), were utilized in both formats. Examples of this imagery are shown later in this report.

In addition to the vertical photography, oblique 35mm color and color infrared photography was obtained during each mission. These photos were taken to document field conditions or cultural practices. Examples of this type of photography are shown later in this report.

Acquisition of the large-scale vertical and oblique photography was scheduled to occur at critical periods throughout the rice growing season. These critical periods were generally defined by changes in phenology (crop calendar) and included:

(a) Field preparation
(b) Flooded fields and rice sowing
(c) Flooded fields with emergence of seedlings
(d) Vegetative growth
(e) Heading
(f) Maturation
(g) Harvest
(h) Stubble conditions.

Each of these discrete periods can be recognized by crop characteristics and appearances such as color, texture and plant density, and cultural practices such as plowing, flooding, and harvesting. The timing of each of these conditions relative to a nominal crop calendar can have a profound effect on yield and it is exceedingly important to document each when it occurs.

The initial intent of the large-scale aerial photography was fivefold. The first was to provide highly accurate measurements of actual rice cropped acreages. Basic to any prediction of yield of any crop on a regional basis is the ability to determine the actual cropped acreages. This acreage would be estimated for each SSU by determining the photo scale, delineating the actual rice cropped area on the photos, then converting to actual rice cropped acreages on the ground. In this way yield predictions based on cropped acreages could be determined for the SSU and expanded to the rice crop region. In actuality, it was found that the NASA-provided aircraft support photography (the RC-10 24" focal length 9x18-inch format at a scale of 1:30,000) was optimal in terms of required resolution and area of coverage.

The large-scale photography was also used to determine specific field conditions. On the smaller scale photography (1:20,000 and 1:30,000), the identification of crop type and <u>general</u> field conditions (e.g., flooded, fully vegetated, harvested, etc.) was possible. However, for the yield-prediction procedure specific field condition, such as relative area of emergence, green headed, etc. were required. The large-scale 9x9-inch photography was designed to yield these types of information.

In order to assess accurately the quantitative impact of yield-affecting factors, it is necessary to determine the surface area affected by the factor. For example, if blast disease was observed in a field, it would be necessary to know what percentage of the field is affected in order to adjust the yield for the field. It was felt the order of accuracy needed for these types of assessments was not available from the smaller scale imagery, thus the use of the higher resolution, larger scale.

The improved resolution characteristics of the large-scale photography also made possible the extension of the area of "ground data collection." The resolution of the large-scale photography usually allowed assessment of such factors as green heading, leaf color, plant density, etc., the types of information being gathered by EarthSat field crews and cooperating farmers. In fact, the large-scale photographs allowed better assessment of entire field condition than ground observations due to the overhead synoptic view. Given the constraints of time and budget typical of most crop survey projects, the large-scale aerial photography greatly extended the areas where detailed crop information was available.

The last function of the large-scale photography, both vertical and oblique, was to record, for reference and illustrative purposes, the appearance of the yield-affecting factors.

15.3.4.2 Ground Data Collection

Ground data collection was accomplished by two different methods. One method utilized farmer cooperation, and the other involved EarthSat personnel.

The individual fields monitored throughout the season with the large-scale aerial photography were generally those operated by cooperating

farmers. These farmers were provided with standard data sheets which asked for the types of data necessary for our evaluation of the actual field conditions. The sheets were pertinent to each of the two study areas, Louisiana and California, asking only for data necessary. The cooperators were asked to fill out the data sheets and return them at the end of the rice season. Examples of the data sheets are presented on the following pages.

EarthSat personnel were also sent into the field at appropriate times to spot-check and describe field conditions and record them with ground photographs. Not as obvious but probably most important was the interaction of the EarthSat field people and the rice farmers. Through conversations with the farmers a great amount of background information was learned which was useful in establishing crop calendars and describing crop appearance. The field personnel were also to be the image analysts for many of the interpretation tasks and the information they derived from these conversations was directly applicable in guiding their interpretive activities. For example in Louisiana, lodging, even late season lodging, is a problem due to the high moisture availability (very conducive to fungi and molds) and generally reduces yield significantly; in California, where it is drier, late season lodging is not as severe a problem and may even be indicative of a higher yield (the heavier heads being more susceptible to blow down). Yet on the data sheets both the Louisiana and California farmers merely indicate the presence and percentage of lodged grain. Without the background information specific to each area, serious interpretation errors could occur.

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OF POOR QUALITY

Field Data Sheets: For each field please record the following types of data.

Field no.: 5.
Date of planting: 5-20-73
No. of acres: 220
Preparation method: plow disk float.

Date of seeding: 5-20-73
Date of germination (if observed): 5-30-73
Variety planted: Caloro
Method of seeding: air

Application of fertilizer

Type	Date	Concentration
N	5-15-73	100 lb
P	5-15-73	100 lb

Application of herbicides or fungicides

Type	Date	Concentrations	Method	Results
Molinate	5-30-73	60 lb granules	air	satisfactory
MCP	5-13	16 oz	air	satisfactory

Water fluctuations

Type of fluctuation	Date	Water condition (clear, muddy)
Constant flood -	5-19-73	Clear

Weed problems

Type	Date	Treatment	% of field affected
Watergrass -	5-15-73	Molinate	100
Broadleaf	7-5 73	MCP	100

Diseases

Type	Date of occurrence	% of field affected	Treatment	Results

Lodging

When occurred	Severity (% of field down)
10-10-73	80 %

Harvest date: 10-15-73
Bulk weight: 5200 pracre
Milling percentages: Fair -

Field Data Sheets: For each field please record the following types of data.

Field no.: 6
Date of planting: 5-15-73
No. of acres: 130
Preparation method: plow disk float.

Date of seeding: 5-15-73
Date of germination (if observed): 5-20-73
Variety planted: Caloro
Method of seeding: air

Application of fertilizer

Type	Date	Concentration
N	5-12-73	100
P	5-12-73	100

Application of herbicides or fungicides

Type	Date	Concentrations	Method	Results
Molinate	5-25-73	60 lb granule	air	satisfactory
MCP	6-20-73	16 oz	air	Satisfactory

Water fluctuations

Type of fluctuation	Date	Water condition (clear, muddy)

Weed problems

Type	Date	Treatment	% of field affected
Watergrass	5-25-73	molinate	100
Broadleaf	6-20-73	MCP	

Diseases

Type	Date of occurrence	% of field affected	Treatment	Results

Lodging

When occurred	Severity (% of field down)
9-1 73	10%

Harvest date: 9-30-73
Bulk weight: 5200 per acre
Milling percentages: [illegible]

Effort was made to include fifteen to twenty fields, totaling 1,000 to 1,500 acres, in each of the four SSUs. This figure was chosen because it seemed an adequate and representative sample for the entire SSU. In addition, it was hoped that the acreages would be dispersed among as many farmers as possible so that a representative cross section of cultural practices could be analyzed. Along with a purposeful dispersal of acreages among farmers, it was hoped that there would be a representative pattern of fields so that the area was covered uniformly.

Generally, the farmer response was good in both Louisiana and California. An exception was in the Butte SSU. Communication problems with the County Extension Agent were the basic reason. Otherwise, the farmers who responded and eventually cooperated showed little unwillingness to release their records and were extremely eager to share in the knowledge gained. A point relative to this is the type of farmers who are generally willing to cooperate. These farmers are generally the better ones, most proud of their farming methods and yields and, therefore, very willing to share information about them. The farmer who will not cooperate seemed to be a little less able with perhaps more cultural problems and lower yields. This characteristic creates a ground data problem because it essentially biased our sample toward the good cultural practices, and away from the desirable objective, the study of yield-limiting factors.

A problem of actual data submittal was also encountered. In many cases, even with repeated follow-up by project staff the ground data needed for progress in the study was received five to six months after the end of the season. This time lag not only slowed project advance, but also compounded the problem of relating ground conditions to photographs of image

appearances. With data being received months after the condition had come and gone, it was nearly impossible to reconstruct or verify some of the data.

Despite the problems, the ground data collection program was successful in terms of farmer participation, readout, and quality of data collected.

15.4 METHODS

15.4.1 IMAGERY AVAILABLE FOR STUDY

The imagery available for the study (including ERTS-1, NASA aircraft support, and EarthSat large-scale) is indicated in Tables 15 and 16. Perusal of these tables underlines the major problem in this study, i.e., the lack of satellite and aircraft coverage in Louisiana during the rice season combined with a major effort in acquiring large-scale support photography. (See Figures 29 through 40.)

15.5 PROPOSED PROCEDURE

In general terms, the procedure to be used in producing acceptable estimates of yield of rice and other grain crops is as follows. (See Figure 41.)

a. By image interpretation or historical reference data, delineate the boundaries of the major crop growing regions and determine their areas. Develop a suitable sampling scheme to monitor "indicator" areas at each of the critical periods described in the next section for the major crop areas.

b. Prepare reference materials and photo interpretation keys, and instruct photo interpreters in the image characteristics and

Table 15 . Status of Imagery Availability for Louisiana Costal Plain Test Site

Imagery Type	Figure Number	Date	Condition or Interpretability	Rice Calendar*
ERTS-1		13 Mar '73	100% cloud cover	
	29	31 Mar '73	Clear; color composite received	a
		18 Apr '73	100% cloud cover	b
	30	24 May '73	30 to 40% cloud cover; color composite received	c
		29 Jun '73	20% cloud cover; test site obscured	d
		22 Aug '73	Clear; color composite received	f
		9 Sep '73	80% cloud cover	g
		27 Sep '73	50% cloud cover	g,h
		15 Oct '73	80% cloud cover	h
Aircraft Support (NASA)		11 Aug '73	2% cloud cover; partial test area coverage	e,f
Large Scale (EarthSat)		31 Mar '73	Excellent	a
		3 Jun '73	Excellent	b,c
		29 Jun '73	Excellent	d
		28 Jul '73	Excellent	e
	52-55, 60	11-12 Aug '73	Excellent	e,f
		14 Aug '73	Excellent	f
		19 Sep '73	Excellent	f,g

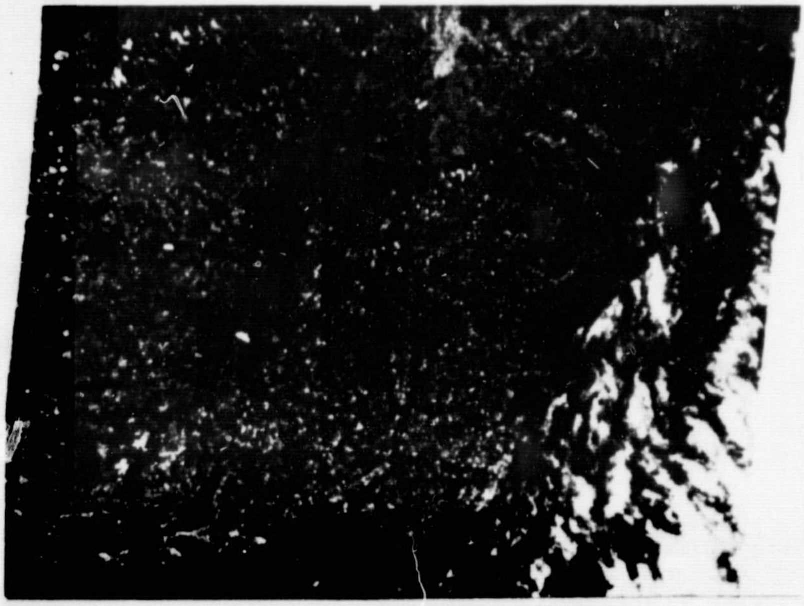
*Legend:

a = Field preparation
b = Flooded fields and rice sowing
c = Flooded fields with emergence of seedlings
d = Vegetative growth
e = Heading
f = Maturing
g = Harvest
h = Stubble conditions

Table 16 . Status of Imagery Availability for Northern Great Valley Test Site

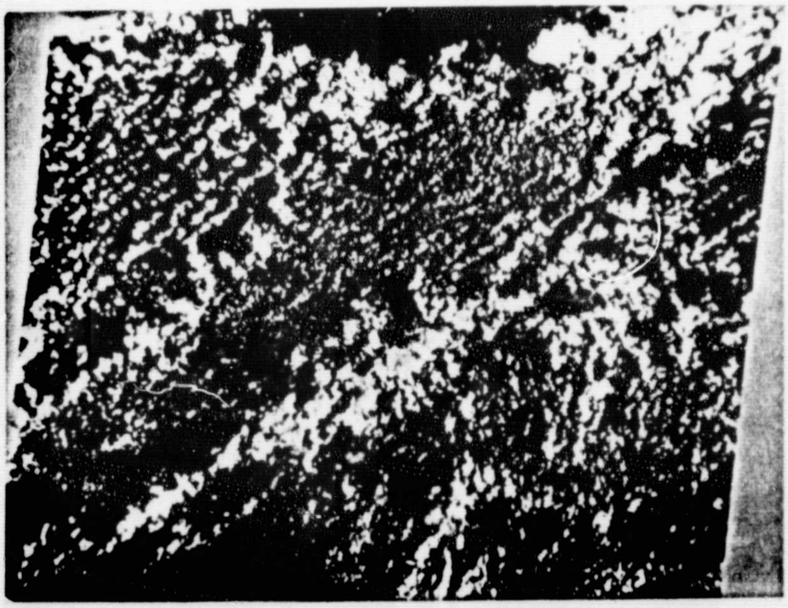
Imagery Type	Figure Number	Date	Condition or Interpretability	Rice Calendar*
ERTS-1		26 Jul '72	Excellent	
		17 Mar '73	Excellent	
		4 Apr '73	Excellent	
	31	22 Apr '73	Excellent; color composite received	a
	32	10 May '73	Excellent; color composite received	b
	33	28 May '73	Excellent; color composite received	b,c
	34	15 Jun '73	Excellent; color composite received	c
	35	3 Jul '73	Excellent, color composite received	d
	36	21 Jul '73	Excellent; color composite received	d
	37	8 Aug '73	Excellent; color composite received	e
	38	26 Aug '73	Excellent, color composite received	e
	39	13 Sep '73	Excellent; color composite received	f
Aircraft Support (NASA)	44	12 May '73	Some overexposed	b
		3 Jun '73	Excellent	c
	45	5 Jul '73	Excellent	d
		12 Sep '73	Excellent	f
	58	10 Oct '73	Excellent	g,h
Large Scale (EarthSat)	43	7 May '73	Excellent	b
		14 Jun '73	Excellent	c
	46	10 Jul '73	Excellent	d
	48,50,51,61	28 Aug '73	Excellent	e
	56	29 Aug '73	Excellent	e
	57,59	13 Sep '73	Excellent	f

*Legend
a = Field preparation
b = Flooded fields and rice sowing
c = Flooded fields with emergence of seedlings
d = Vegetative growth
e = Heading
f = Maturing
g = Harvest
h = Stubble conditions



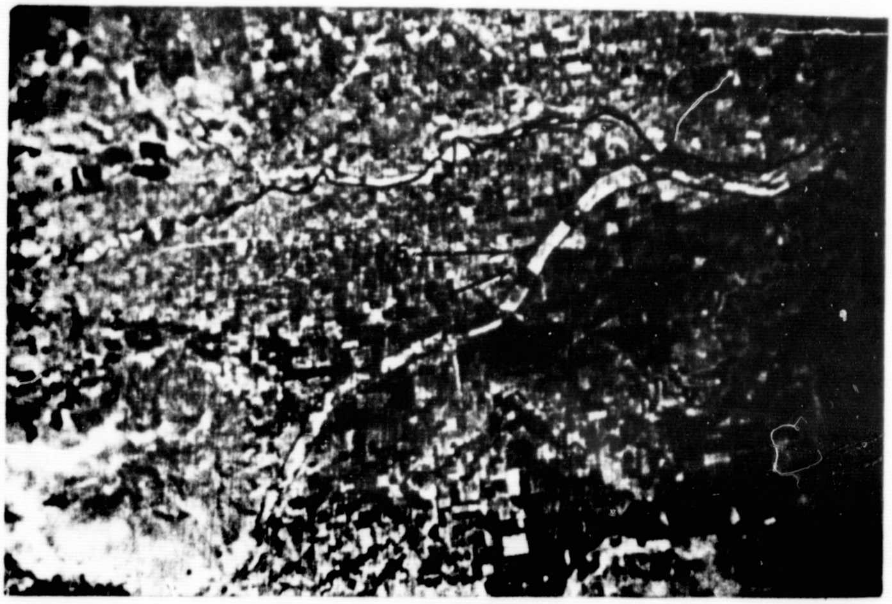
ERTS-1 Bands 4, 5, 7
March 31, 1973 ID 1251-16142

Figure 29. Photo of Louisiana Coastal Plain study area taken as field preparation is just beginning. Heavy rains delayed field preparation and planting in the test area. This was the only clear coverage of rice test area until August 22, 1973.



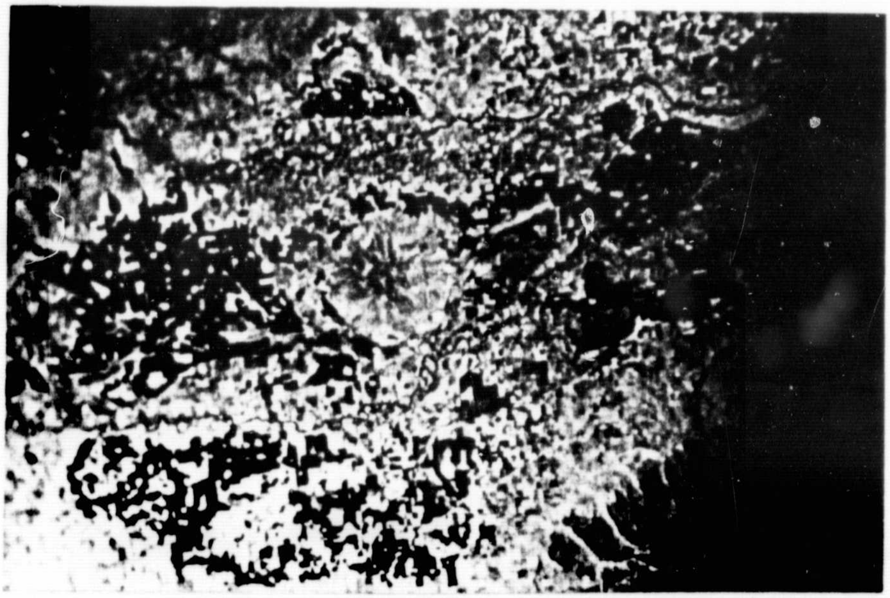
ERTS-1 Bands 4, 5, 7
May 24, 1973 ID 1304-16140

Figure 30. This photo was taken when typical cloud formations were present over Louisiana Coastal Plain test area. Area covered is essentially the same as previous Figure.



ERTS-1 Band 4, 5, 7
April 22, 1973 ID 1273-18180

Figure 31. Rice land in this California rice growing area has been prepared for planting and appears as various shades of gray. Fields within the grey areas that appear red in color are, in most cases, winter grain crops that on subsequent dates (May 10 and May 28) have matured and are being harvested. A few of the red fields are cover crops soon to be cultivated for planting. Comparison of this photo with those on subsequent pages emphasizes the importance of correlating sequential photography with data on crop calendars for crop identification and evaluating crop vigor and stress. Note that a few fields have been flooded and appear dark blue or black. Fields at arrows appear in Figures 43-46 and 56-58 on aircraft support photos.

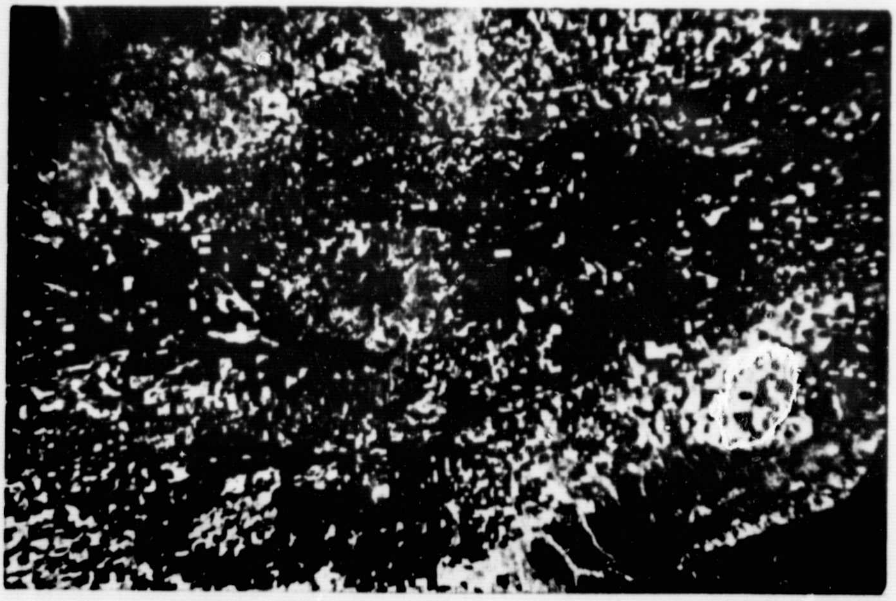


ERTS-1 Bands 4, 5, 7
May 10, 1973 ID 1291-18175

Figure 32. Rice fields are being flooded as indicated by the change in color from grey on the April 22 photo to dark blue or black on this photo. By noting those fields that are flooded early in the growing season (the month of May in California) it is possible to identify those fields on which rice will be grown that year. Note those fields within the dark blue areas that appear red are crops other than rice grown through the winter and early spring and will not be planted to rice in that year.

ERTS-1 Bands 4, 5, 7
May 28, 1973 ID 1309-18174

Figure 33. Rice primary sample unit and four sub-sample units in Northern Great Valley. Note that the two major changes in the scene in the 36 days from the April 22 photo relates to rice fields (dark blue) having been flooded (and in most cases planted) and the maturing and harvesting of many of the fields of winter grain or cover crops. Such fields have changed from red on April 22 coverage to tan on this photo. By this date all rice fields should have been planted and in some early planted fields rice will have emerged above the water. In the small sub-sample unit at upper left a few fields exhibit a reddish color as the new rice crop covers the water.



ERTS-1 Bands 4, 5, 7
June 15, 1973 ID 1327-18173

Figure 34. At this date many rice fields appear red and are easily confused with fields where other crops are grown. In a few fields thin rice stands can be detected indicating reduced plant vigor and/or density.

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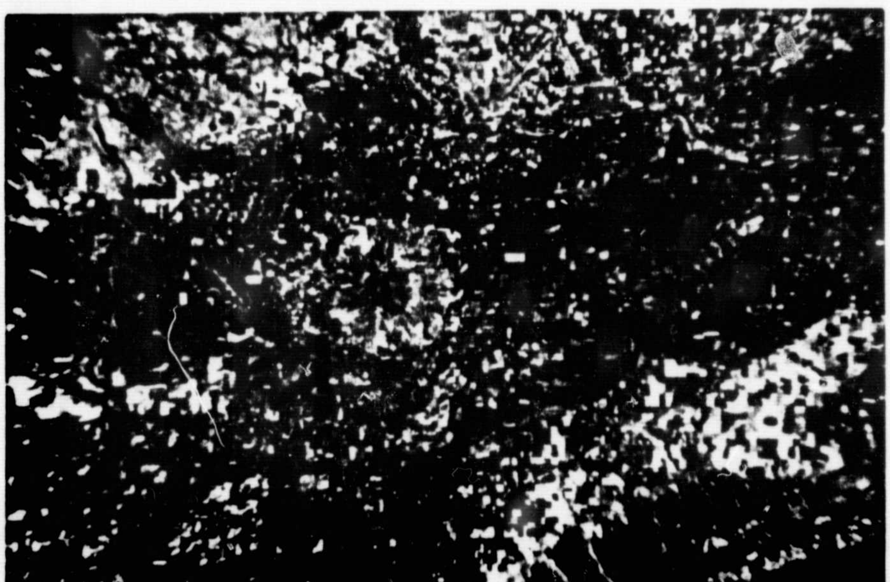
ERTS-1 Bands 4, 5, 7
July 3, 1973 ID 1345-18172

Figure 35. All rice fields will appear red on this date. In some cases thin stands of rice can be seen as non-uniform red color in fields. These areas will result in some reduced yield but there are many other areas too small to see on ERTS photos that also will have reduced yield. Thus, larger scale photographs are needed of selected locations for detailed analysis.

ERTS-1 Bands 4, 5, 7
July 21, 1973 ID 1363-18171

Figure 36. The rice fields at this date appear to be very vigorous and few locations of reduced stand can be seen indicating a potential high yield. Note how difficult it is to separate rice from other crops at this time.



ERTS-1 Bands 4, 5, 7
August 8, 1973 ID 1381-18165

Figure 37. Rice fields which have headed appear as pinkish color as contrasted with those red fields not yet headed. Analysis of the fields flooded earliest and appearing red at an early date indicates those fields are the ones appearing to be headed at this date. Recognition of heading is an important input to the yield estimating question.

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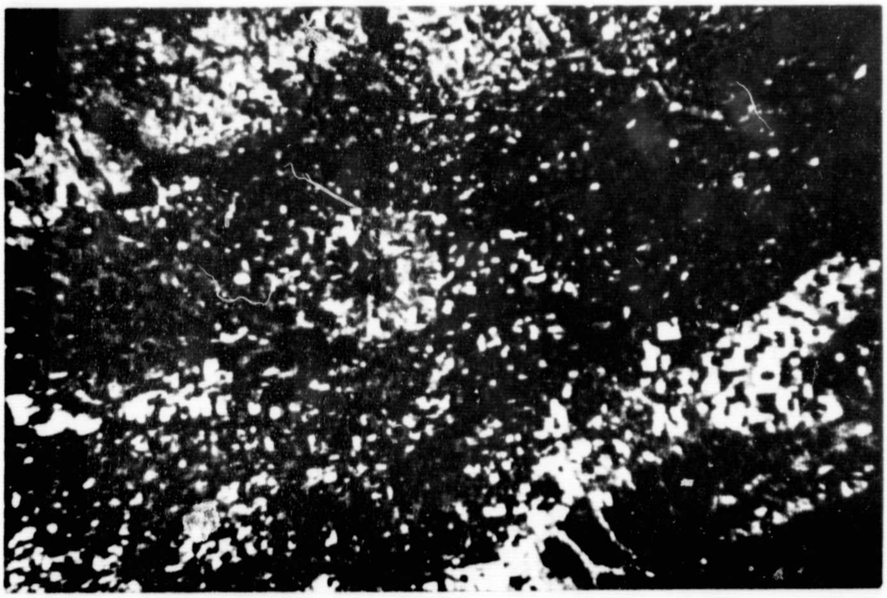
OF POOR QUALITY



ERTS-1 Bands 4, 5, 7
August 26, 1973 ID 1399-18163

Figure 38. There are an increasing number of headed rice fields at this date and some indication of early maturing rice fields. Care should be taken in plotting maturing rice fields because other crops such as milo and safflower, grown in association with rice, may also be maturing and cause some confusion where rice fields have not been previously identified.

ERTS-1 Bands 4, 5, 7
September 13, 1973 ID 1417-18161

Figure 39. The rice fields which appear pinkish at this date are maturing and soon will be harvested. Interpretation of the ERTS photos to date indicates that rice production should be high with very few problems. Information received from cooperators indicated that this was the case.

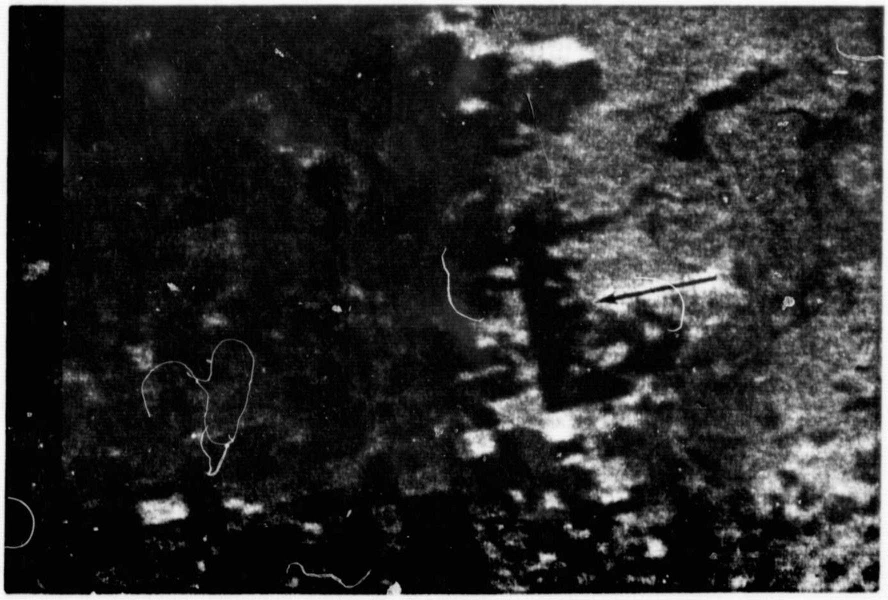


Figure 40. ERTS-1 additive color with Band 5 from two different years; July 26, 1972 projected with red filter, August 8, 1973 projected with green filter.

Crop	Color Legend July 26, 1972	August 8, 1973
Rice	Black	Black
Other	Red	Green

If rice was present both years, image is black.
If rice was present in 1972 and not in 1973, image is green.
If rice was present in 1973 and not in 1972, image is red.
If rice was absent both years fields are tan.

Note warming basin for irrigation water is dark feature at far right.

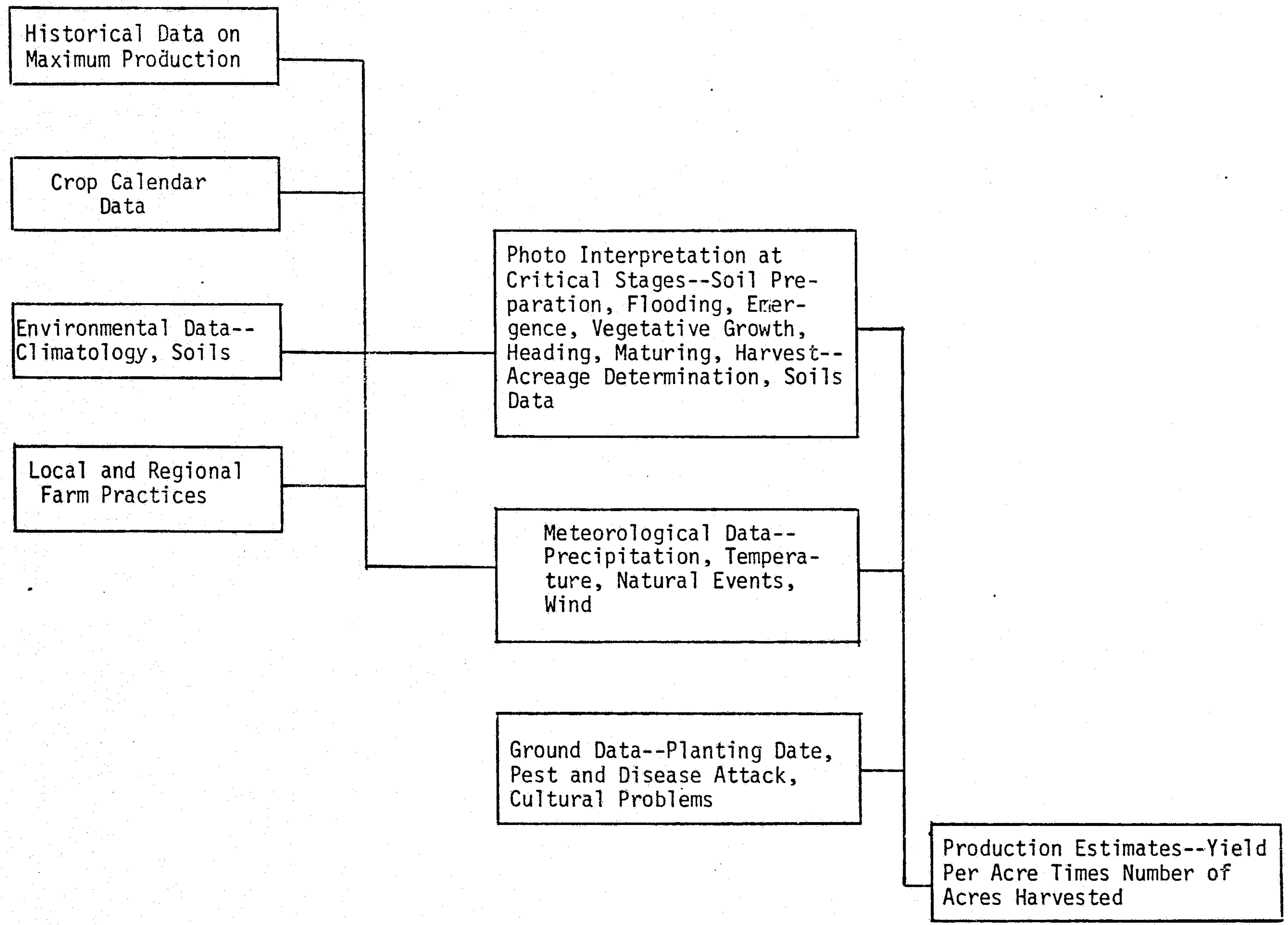


Figure 41. Flow Diagram for Rice Yield Information.

crop signatures that are to be used for interpreting space and aerial photos.

c. Obtain color infrared* photos at four or five critical periods during the growth of the grain crop coinciding with (1) soil preparation prior to planting, (2) full cover of ground (water) by plant foliage, (3) full foliage growth immediately prior to emergence of fruiting bodies, (4) mature green crop immediately prior to yellowing, and (5) optional coverage immediately prior to harvest in the event serious crop damage has occurred since the previous coverage by weather factors.

d. By photo interpretation determine when an anomaly (area of reduced plant vigor) appeared in a particular field and judge the identity extent and severity of that anomaly. This determination is made by searching for non-uniform features within a given field such as color variability, texture differences, and uneven plant density (e.g., soil deficiency causes chlorosis and stunting, appears early and does not spread; disease causes loss of vigor, stunting and will spread from a mid-season start). Area of crop and of anomalous images within crop fields are usually determinable by visual methods, digital scanning techniques or electronic image enhancement devices.

e. Using the best estimate of <u>maximum</u> potential yield for the rice crop being grown in the given region (i.e., assuming all crop production factors were optimum and thus no yield-reduction

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*Other film/filter combinations are less useful and may not provide needed image contrast.

occurred), compile yield estimates at each photo date by a subtractive process from the maximum potential yield based on photo interpretation information. Thus, at each date of photography an accurate estimate would be made of the yield from the region under consideration thereby assuming that all remaining factors and growth conditions would be optimum. As each phase of photography is interpreted, a new yield estimate would be made by the subtractive method reducing the previous estimate by only those factors which were newly visible or became more severe.

15.6 CONCLUSIONS

15.6.1 SYSTEM REQUIREMENTS

Several of the factors that tend to reduce the yield of agricultural crops can be assessed on aerial photography. These factors include the presence of various insects, diseases, weeds, mineral deficiencies, and mineral toxicities as well as drought, flooding, sunscald, frostbite, and wind-throw (e.g., lodged grain).

In order to assess accurately on aerial photos the degree to which each of these factors affects crop yield, it is imperative to take the photography to appropriate specifications which will permit detecting the extent and severity of each factor. For rice crops the bands exploited in color infrared photography provide tonal values suitable for making these determinations. (See list on following page.)

Furthermore, the photographic scale must be large enough to make the necessary determinations yet small enough to permit use of the method at flight altitudes which the user will consider operationally feasible. Also, it is essential to photograph the crop areas during times when each of the

ADVANTAGES AND LIMITATIONS OF ERTS, EREP AND SUPPORTING AIRCRAFT PHOTOGRAPHY

IMAGE TYPE	ADVANTAGES	LIMITATIONS
ERTS MSS	Broad area coverage on a repeatable basis. Excellent spectral capabilities. Data are computer compatible.	Resolution limited to regional interpretations to a ten acre minimum size. Imagery not useful for day-to-day crop management decisions on a farm basis. Time constrained.
High-flight Photography	Medium area coverage on a scheduled day-to-day basis. Cameras and spectral bands readily changeable. Spatial resolution permits semi-detailed interpretation for crop analysis and management decisions on a two-to-three acre basis and larger.	Requires careful flight planning and execution to insure correct coverage. Cannot cover as large an area as with spacecraft.
Low-flight Aircraft	Small area coverage on a scheduled day-to-day basis. Cameras and spectral bands readily changeable. Spatial resolution permits detailed interpretation for crop analysis, evaluating plant stress and vigor and making management decisions on a less than acre basis.	All factors listed for high-flight aircraft apply here. Areas covered are even less. Repeatability of ground track becomes a problem.

yield-reducing factors can be accurately assessed. A limited amount of field checking is required to provide a basis for determining the accuracy with which the extent and severity of each factor can be determined by aerial photo interpretation. This field checking also permits yield-reduction factors to be determined for the various photo identifications made.

In most cases, yield estimates on a field-by-field basis cannot be made using ERTS images alone because of the limited resolution characteristics of ERTS data. Many of the yield-limiting factors occur in small areas and are scattered so that they are not detectable on ERTS images.

In a comparative study of Skylab and ERTS imagery[1] it was found that the minimum agricultural field sizes consistently detectable on ERTS imagery were in the 10-to-40-acre range depending upon contrast with surrounding features. Thus, problem areas occurring in small patches are not detectable on ERTS images. In those cases, higher resolution images such as those provided by aircraft camera systems are needed to reveal the presence of crop limiting agents.

15.6.2 PARAMETERS DETERMINING YIELD

The three primary factors affecting yield determinations as made, field-by-field, on photography are field area, plant density, and plant vigor.

15.6.2.1 Field Area

Field area can be measured directly on aerial photos by various means. On ERTS photos, area measurements may be made on groups of fields where

[1] A Comparison of Skylab and ERTS Data for Agricultural and Natural Vegetation Interpretation Technical Report, July 1, 1974, Earth Satellite Corporation. NASA Contract No. NAS 9-13286.

field sizes are too small for individual delineation. In this case a correction factor is frequently applied to compensate for roads, farm buildings, and irrigation and drainage canals that are included. The making of field area measurements is essentially a mechanical process once the crops have been identified and their boundaries delineated. Among the devices most commonly used in measuring field areas on vertical photos of known scale are:

a. The polar planimeter. An initial reading is made on the planimeter's dial. A pointer attached to one end of the planimeter's arm is then used to trace out the field's photo boundary, thereby changing the reading on the dial. The difference between initial and final readings on the dial provides a measure of the field's area.

b. The dot grid overlay. Each of the uniformly-spaced dots on a transparent plastic overlay represents a known field area, depending on photo scale and dot spacing. The overlay is randomly oriented over a vertical aerial photo on which the field's boundary has been delineated. The total number of dots falling within the field is multiplied by the calculated area represented per dot to estimate the field's area.

c. The line transect overlay. Each unit of length on each of the uniformly-spaced lines of a transparent plastic overlay represents a known field area, depending on photo scale and line spacing. The overlay is randomly oriented over a vertical photo on which the field's boundary has been delineated. The total number of line units falling within the field is multiplied by the calculated area per line unit to estimate the field's area.

d. The laboratory balance. A square which, at the scale of the vertical photo, represents some convenient unit of area (e.g., one square kilometer) is delineated directly on the photo. Usually this is done somewhere in the corner of the photo where no fields that are to be measured appear. Using scissors or a razor blade, this square is carefully cut from the photo and weighed on the laboratory balance to establish a weight per unit field area. Each field in turn, for which area is to be determined, is then cut from the photo and weighed. This weight, divided by the weight per unit area, provides an estimate of the field's area.

e. The density slicer. By electronic image enhancement and determination of percent of area of each density on the film, a relative area of each crop type can be estimated.

f. Digital image readout. In those cases where digital tapes are available, such as for ERTS or airborne multispectral scanners (MSS), area determination for particular image features having characteristics recognizable by the digital signature can be made by a computer program compatible with a tape reader.

15.6.2.2 Plant Density

Plant density for any given field is defined as the percent of the total ground area within the field that is covered by foliage as seen in the vertical view. The state of the development of the crop must be considered in ascribing significance to a plant density figure.

Certain soil characteristics can greatly affect plant density. Principal among these are soil fertility, soil depth, physical structure and moisture content. Soil which has an optimum level of these factors will support a relatively high plant density and can produce a crop of

high yield. Increasing the plant density above this level (e.g., by seeding the area too heavily at planting time) will result in a reduction in yield due to the increase in foliage competition for sunlight, and in root competition for nutrients and water. By the same token a decrease in plant density will not fully utilize the carrying capacity of the soil although individual plants will produce well.

Therefore, in agricultural crop management it is important to determine the soil producing capacity for the particular crop to be planted and establish a crop with the desired plant density for the prevailing conditions. Fertilizer, humus, minerals and other materials can be added to the soil to increase crop production up to the maximum level for each factor beyond which a loss in yield will result.

It is difficult to assess on space photography what this optimum plant density level might be due to the complex interrelations that occur. However, it is possible to compare existing plant densities within a field or among several fields appearing on space photographs and to evaluate the relative characteristics, within the various plant density strata, which indicate potential yield such as heading (on cereal crops), foliage color and height. Among the factors which affect plant density are seeding density, seed viability, seed germination, seedling survival and the use or misuse of planting and cultivating equipment. In estimating plant density, the photo interpreter estimates the area of visible foliage structures covering the background soil or water and thus the integrated effect of these factors on crop yield.

15.6.2.3 Plant Vigor

Plant vigor is variously rated in relation to foliage tone or color, plant size and rate of growth. While it is generally true that the more vigorous plants produce a higher yield, other factors are of importance. For example, the faster growing, denser, more vigorous, and more succulent plants may be more susceptible to attack by diseases. Wind damage is also greater in cereal crops which exhibit these characteristics. Therefore, vigor determinations provide a good basis for yield estimation but only when the other previously-listed factors related to vigor are known or are determinable. In attempting to relate apparent plant vigor to crop yield, it is important to know which of the previously-listed damaging agents may have contributed to a loss in vigor.

Probably the most important agents responsible for reducing plant vigor and, thereby, crop yield are those collectively known as "plant pests." It has been determined that in the United States alone about 15 billion dollars annually are lost to the agricultural and forest economy due to the activities of such pests.[1] Each year, about 20 percent of the food crops of the world are never harvested for the same reason. Only in very severe cases of pest attack would crop damage be detectable on ERTS photos. On aerial photographs, some of these plant pests are readily identifiable and their effects on crop yields determinable, while others are very difficult to identify and assess in relation to yield reductions. Even the agronomist on the ground may have difficulty in

[1] "Report of the Committee on Plant Pests," National Research Council - National Academy of Sciences, 1961.

detecting these pests and in assessing their severity, extent, and effect upon yield of the crops attacked.

15.6.3 SUPPORTING DATA

Some of the variables encountered in producing agricultural crops can change the potential yield of a field with little change in the visible appearance of a crop. In such instances, historical crop data will prove useful, especially in making regional yield determinations. Other variables include information such as crop yield trends for a region over the past ten years, weather data prevailing during crop establishment and at critical periods of crop growth, and indications of increased planting of a crop in areas not normally committed to that crop.

15.6.4 THE SUBTRACTIVE METHOD OF YIELD ESTIMATION

The photo estimation of yield for a particular crop in a designated region is greatly facilitated if one knows the maximum potential yield which that crop can produce when grown in the region being investigated; i.e., the yield that would be obtained if all potentially limiting factors were absent. Such a condition rarely exists, but information on the potential yield permits a very useful datum to be established. As the various yield-limiting factors are detected on photos at various stages in the development of a crop, appropriate deductions can be made systematically from the potential maximum yield.

In using the technique of reducing yield from a potential maximum, two assumptions are made: (1) given a supply of viable seed typical of the variety grown with success in the study area and a plot of ground properly

prepared for growing that crop, the farmer has, at the outset, the potential of growing a nearly perfect crop with a known maximum yield, and (2) from the day the seed is sown certain yield-limiting factors may become operative.

These factors may be segregated into physical effects and physiological effects. The physical effects pertain to the actual presence or absence of crop-producing plants in any part of the field. Obviously, a complete absence of plants will cause a 100 percent yield reduction for the area involved.

The physiological effects pertain to the presence of pests or other factors which affect the health and vigor and, hence the yield, of the crop. These factors may affect yield in decidedly different ways depending upon the severity of each factor and the time in the growth cycle of the crop when each took effect. Since the limitations caused by physiological effects cannot be expressed in areas where no plants are present, data reduction processes for each of the types of yield reduction should be considered separately. The loss caused by physical effects can occur at any time during the growth of the crop and can reduce the yield by as much as 100 percent, should physical forces completely eliminate producing plants. On the other hand, yield reductions caused by introduction of physiological effects are greatest at certain periods during the growth of the crop and at other times introducing the same physiological agents will have a relatively small effect upon yield because the crop may have grown past the stage of susceptibility.

The technique described on the following page is based on results actually obtained for rice during tests conducted by the present investigators. It illustrates a typical use of the concepts just described.

POTENTIAL YIELD

TECHNIQUE OF DATA REDUCTION

(EXAMPLE)

AREA - Sutter Test Field No. 5
Colusa Variety
220 acres, planted 20 May 1973

PHOTO DATES	5 July 1973, 29 August 1973	PHOTO SCALE	1/30,000
FILM-FILTER	Ekta Infrared /Wratten 12	PHOTO QUALITY	- Good

POTENTIAL YIELD — 6,000 lbs/Acre

YIELD REDUCTION FACTORS:

A. Physical

Inadequate Seeding	5
Improper Cultivation	0

Total Yield Reduction due to Physical Factors = 5% x 6,000 = 300 lbs.

Maximum Field Potential Remaining = 5,700

B. Physiological

Disease	0
Lodging	0
Weeds	10

Total Yield Reduction due to Physiological Factors = 10% x 5,700 = 570 lbs.

NET YIELD EST BY PI	5,130 lbs/Acre
ACTUAL YIELD FROM GROWER	5,200 lbs/Acre
ERROR IN ESTIMATE	-70 lbs/Acre
ERROR IN ESTIMATE	-1.4%

The realistic assumption made in this example is that, in the vicinity of Sutter, California, the "maximum potential yield" of one variety of rice was 6,000 lbs./acre. It will be noted that appropriate reductions in yield were made in the various fields, on various dates, as photo interpretation established the presence and severity of various harmful physical and physiological factors.

15.6.5 DESCRIPTION OF PHOTO DATA REDUCTION TECHNIQUE

The usefulness of aerial and/or space photography for agricultural crop observation has been an established fact for many years. The facts which have not been established pertain to the reliability of estimates of specific crop factors such as: (1) crop vigor and health, (2) type of disease, severity and extent, (3) response of crops to applications of mineral nutrients, herbicides, insecticides, etc., (4) effects on crops of natural influences such as microclimate, storms, floods, etc., and (5) estimated yield in light of these and other factors.

15.6.5.1 Image Factors

Images of crops can be used for analysis of crop condition if certain facts have been established for the crop in a specific region. These image factors are: (1) relative tone or color of the vegetation, (2) density of the vegetation covering the ground, (3) texture and uniformity of images, and (4) appearance of the crop on sequential photographic coverage.

Although some of the factors which influence the growth of a crop and the ultimate yield attainable in a given area and season can be recorded on space photography taken to proper specifications, it is nearly impossible to separate each of these factors when they occur simultaneously on the same area. Some of these factors affect yield to a high degree, while

others may have only a very limited effect on yield. The time when each of these factors occurs, and its severity, also influence the effect on yield.

15.6.5.2 Ground Observation Versus Photo Interpretation

The agricultural expert on the ground, given enough time to observe a crop exhaustively, can estimate the effect of each factor on yield and specify measures for control of some of these factors. In the present rice study, aerial photo dates and exposure specifications were determined by reference to past crop studies and by consultation with experts in the areas where these crops were grown. Thus, the frequency of observation and the image records to be obtained were established before each of the critical events took place.

The influence of each of the anticipated events on the crop and its ultimate yield were determined by consultation with these same experts and by reference to pertinent literature. The major limitations to this technique lay in the inability of the photographic image to record every detail of crop condition at the photographic scale ratios desired, and in the inability of the photo interpreter to separate successfully each of these factors from the others.

For example, in the case of wheat stripe rust, the ground observer, using long-established standard procedures, estimates the amount of leaf area affected by the stripe rust pathogen and, depending upon state of development of the crop, subtracts a certain percentage from the final yield. Thus, if the disease attacks just prior to heading, he has learned empirically to subtract the amount of leaf area infected in percent, divided by three, from the total yield. For example, if he estimates

that 20 percent of the leaf area is infected with stripe rust, he would estimate approximately a seven percent reduction in yield due to this factor. If the photo interpreter estimates 20 percent of the leaf area infected and thus divides this figure by three to obtain the yield-reduction factor, an error will result because of his inability to estimate accurately from the photo image the total leaf area infected.

His ability to determine accurately this factor depends upon the previously-mentioned photo image factors and photo interpretation techniques. In one case it was found that in order for the photo interpreter to judge, by viewing aerial photos, that 20 percent of the total leaf area was infected, there actually had to be at least 60 percent of the leaf area infected. This is due to the inability of the photo system to record every leaf in the necessary detail. Thus, in the case where 60 percent of the leaf area was infected, it was not accurate for the photo interpreter to divide by three his estimate of 20 percent leaf area infected; instead he should consider 20 percent directly as the yield reduction. The ground observer's estimate of 60 percent infected leaf area, however, was divided by three to obtain indirectly a 20 percent reduction in yield.

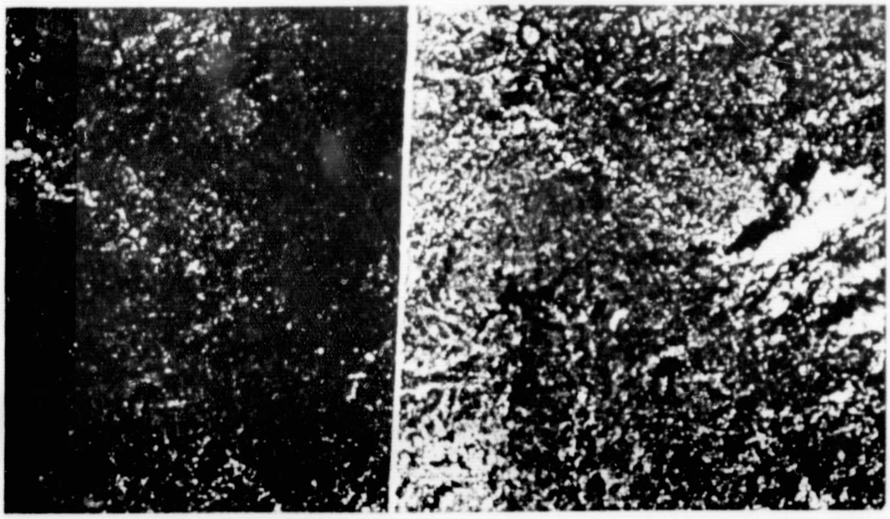
This is only one example of the relationships which were developed during the conduct of one of our earlier programs and which were vital to the success of the program. Many correlations must be made to relate the photo interpreter's estimate of the extent and severity of each of these factors to the actual reduction in yield. It has been necessary in some cases to group many of these factors together because of the inability of the system to separate each factor, and subsequently to develop a relationship to yield reduction for these observations.

Because of the relatively low spatial resolution of ERTS images, most of the commonly encountered yield-limiting agents (i.e., not of disastrous proportions) are not visible on ERTS images. Only in those cases where factors affect large regions, such as drought or widespread storm damage, will they be revealed by ERTS images. A comparison of ERTS color photos taken in north Texas one-year apart, in mid-springtime 1973 and 1974 (see Figure 42), illustrates the ability of ERTS color composite images to reveal the influence of extended drought periods on natural vegetation.

For all but the most severe and widespread crop limiting agents, larger scale images with higher spatial resolution than those possible from ERTS-1 are required. These are usually obtainable from aircraft using high-resolution camera systems. Thus, the use of a multistage sampling scheme offers a method to evaluate the factors needed in estimating crop yield.

15.6.5.3 Multi-image Photo Interpretation

A data reduction technique which has proven to be very useful in increasing the accuracy of yield estimates involves the combining of various crop factor estimates made on photography taken at several dates, and based on photos from several spectral bands. For example, early in the growth of a crop the failure of some plants to become established is visible, thus causing nearly 100 percent yield reduction in these open areas. At a later date, some of the surrounding vegetation may have become lodged or wind-thrown in such a way as to cover and, thus obscure from the overhead view, these previously bare areas. Therefore, a reduction of yield for such areas cannot be detected on aerial photos if photography taken at the later date is the only photography available. If early season



April 5, 1973 March 31, 1974
ERTS-1 Bands 4, 5, 7

Figure 42. Two ERTS-1 photos of Young County, Texas, a major wheat growing area, taken one year apart illustrate the contrast between a period of above-normal rainfall (1973 on left) and a severe drought period (1974 on right). Only the irrigated fields appear to be a normal red color in the drought affected area. Lower levels of reservoirs are also apparent on right-hand photo. This type of comparison is very graphically portrayed by ERTS type images and would be difficult if not impossible to make using aircraft photos because of large areas involved. Note differences in appearance of natural vegetation in nonagricultural areas--an important consideration for livestock managers.

photography is used for stand establishment estimates and incorporated with later photography, when other factors become visible, a greater accuracy in yield estimates will result.

Multiband photography provides more information to the photo interpreter than does broad single-band photography. When ERTS Bands 4 (Green), 5 (Red), and 7 (Near Infrared) are combined in a color additive composite, considerably more information is revealed to the interpreter than when any single band is used.

15.6.5.4 Ground Truth Acquisition

The acquiring of accurate, timely ground truth is an essential part of crop inventory and analysis. Remote sensing data can provide signatures that are consistently recognizable and that correlate with crop production, but it is necessary to have detailed data on the characteristics and components of the various discrete signatures for proper data reduction and synthesis. Ground data are best obtained with photos in hand taken within a few days of the ground visit. It is then possible to correlate more closely the photo images with their true ground counterparts and to relate these data to the reliability of the photograph for crop analysis. In this study ground data collection involved identifying the various crops grown in the test area on a field-by-field basis and determining acreage, planting date, application of fertilizers and herbicides, and data on weeds, pests and other limiting agents. These data were provided by cooperating farmers and by project staff who visited the test sites periodically.

Ground truth for signature identification obtained in one region can be extended to other regions if environmental conditions are similar and where cultural practices, crop varieties, and crop calendars are analogous. However, one should use care in direct application of ground truth outside the area where it was obtained for such factors as effects of various chemical additives and response of crops to pests and diseases in yield estimation. Also, the maximum potential yield of a crop can vary when it is planted in different locations.

Ground truth is obtained most effectively when a sampling procedure is used based on a multistage sampling scheme. In this way it is possible to obtain data that can be used by statistical methods more nearly to reflect the overall crop conditions than if a haphazard approach is used. There will be situations where unusual events occur, such as natural disasters or man-caused events, that will require visits to sites not planned in the sampling scheme to determine the effects, and perhaps the identity, of conditions seen on the photographs or reported by cooperating farmers.

15.6.6 FACTORS WHICH CONTRIBUTE TO ERRORS IN PHOTO INTERPRETATION AND METHODS OF CONTROLLING THESE FACTORS

15.6.6.1 Crop Condition

As discussed in a previous section, the greatest error in yield estimation by photo interpretation results when numerous yield-limiting factors occur in a crop at the same time. The factors listed in subsequent sections bear upon the ability of photo interpretation to produce accurate estimates of yield of a crop in any state of health.

15.6.6.2 Film/Filter Combination

The results of this study on rice and some of our earlier investigations conducted on both rice and wheat indicate that it is essential to acquire photography with the proper film/filter combination for detecting each of the yield-limiting factors, and that no single portion of the photographic spectrum can be used for all of the desired identifications. Experience has shown that three bands can be used successfully for crop interpretation. These bands are utilized on Ektachrome Infrared film--green, red and near infrared--and in the multiband system of ERTS-1.

15.6.6.3 Photo Date

Accurate estimates of crop yield are dependent upon the ability of the observer to determine the time during growth of the crop when the yield-limiting influences are operative. Thus, it is essential to specify photographic dates that coincide with periods when the significant yield-limiting influences can be accurately assessed. From such photography one should be able to establish: (1) the approximate date of first attack, and (2) the rate and extent of spread of the damaging agent as the crop develops, under the influence of various environmental factors such as temperature, humidity, and wind. Critical dates in the rice crop calendar for obtaining photography are emergence, pre-heading, full heading and pre-harvest (mature).

15.6.6.4 Photo Scale

It is apparent from this study as well as our earlier crop investigations that use of smaller scales of photography can result in some error in detecting yield-limiting factors and thus in estimating yield

by photo interpretation. In some cases photo enlargement or viewing of film with magnifiers can be performed on small-scale, high-resolution photos to permit photo interpretation accuracies very comparable to those obtained from larger photographic scales. Generally scales 1:3,000 to 1:5,000 are needed for detailed crop study and 1:30,000 to 1:60,000 for more general study using aircraft photography. Commonly used aerial cameras provide adequate image detail at these scales.

15.6.6.5 Photo Quality

Various factors will limit the quality of the photo image obtained of agricultural crops from either aircraft or spacecraft. These factors include exposure settings, atmospheric conditions, sun angle, camera system resolution, film resolution, filter characteristics, image motion limitations, camera vibration, and photographic processing and printing techniques. Imagery degraded by the existence of less than optimum levels of any of these factors can seriously limit the usefulness of the photographic image for yield estimation by photo interpretation. Thus it is essential to have reasonably good weather at the time of photography and to employ suitable photographic materials, camera systems, flight parameters, exposure controls, image motion compensations and care in processing and printing techniques.

15.6.6.6 Photo Interpretation Techniques, Reference Materials and Keys

The development of appropriate photo interpretation techniques, reference materials and photo interpretation keys is essential if crop condition information suitable for estimating yield is to be produced by means of photo interpretation. In addition, proper techniques of

photo interpretation and proper uses of photo interpretation aids should be taught in special training courses given to those who are to perform operational studies of crop yield in order to assure maximum accuracy of yield estimates made by photo interpretation.

15.6.6.7 <u>Data Reduction Techniques</u>

Data obtained from photo interpretation, historical crop information sources, weather observations, and other data sources must be analyzed in a manner suitable for compiling accurate yield estimates. Correlation of photo interpretation yield data with yield data produced by ground observers also must be accomplished.

15.6.7 VALUE OF HISTORICAL DATA

The acquisition of historical data concerning expected maximum yield from a crop in a particular growing region and the losses generally anticipated from yield-limiting influences such as pests and storm damage will facilitate the making of accurate yield estimates. Such information is essential as a basis for establishing a correlation between image factors and crop condition. The data should be updated from season to season as new varieties are introduced, and new growing techniques are applied (including application of herbicides, fungicides, pesticides, and chemical nutrients).

15.6.8 SUMMARY OF REQUIREMENTS FOR USEFUL YIELD ESTIMATES

In order to estimate yield of a rice crop, it is essential to detect the occurrence of various limiting factors which tend to reduce the vigor (and thus the yield) of plants during the growing cycle. Vigor reduction can be in the form of retarding of growth caused by various

factors such as cool temperature, drought, disease, insect damage, improper water management, mechanical damage, improper chemical application, or insufficient mineral nutrition. Various degrees of each of these factors may occur, depending upon the plant's ability to tolerate conditions of environment and due to cultural practices in crop production.

Useful yield estimates usually require:

(a) Multiband photography in spectral zones typical of Ektachrome infrared film

(b) Proper scheduling of sequential photo coverage

(c) Historical data regarding crop yield and growing conditions

(d) Suitable photo interpretation reference materials and keys

(e) Adequate training of photo interpretation personnel

(f) Appropriate data reduction techniques.

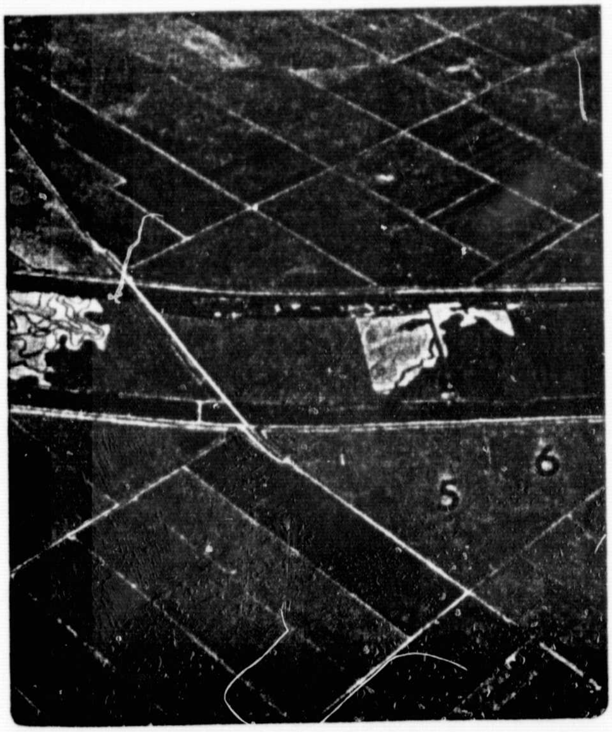
15.6.8.1 <u>Recommended Photo Dates</u> (See Figures 43-61)

(a) For determining plant density: 30 to 45 days after planting

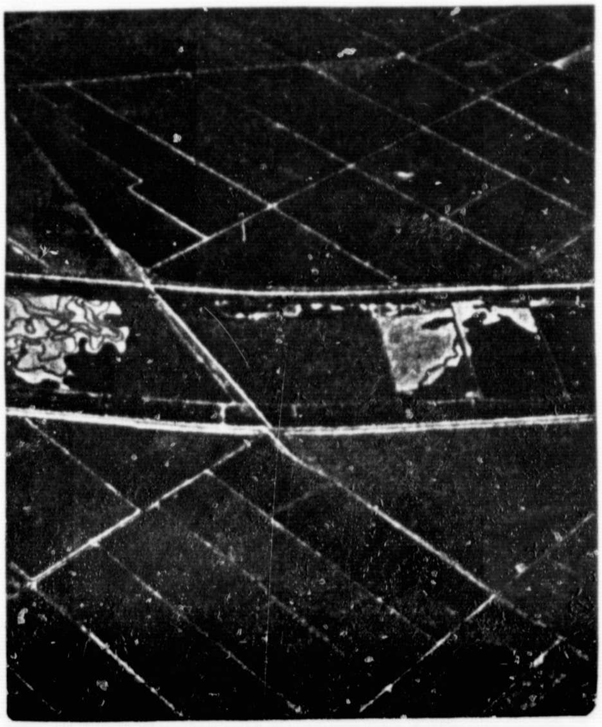
(b) For determining seedling survival: 30 to 45 days after planting

(c) For detecting soil toxicity and assessing mineral nutrition: 30 to 60 days after planting

(d) For estimating disease damage: 60 to 100 days after planting

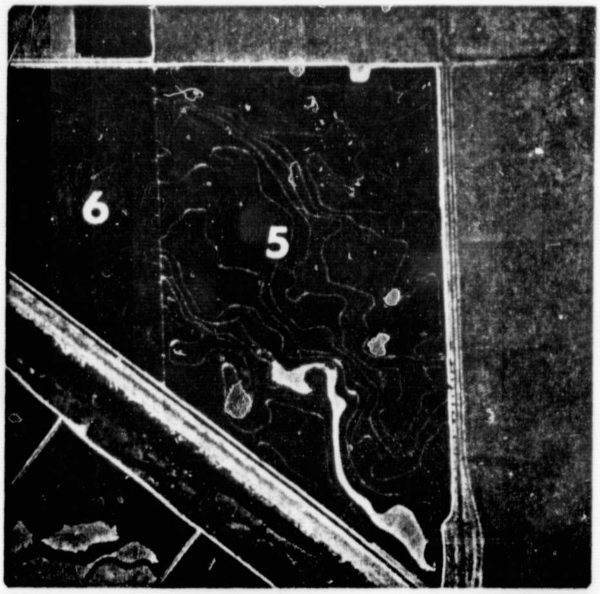


Color Oblique
May 7, 1973



Color IR Oblique
May 7, 1973

Figure 43. Fields 5 and 6 correspond to the data noted on the forms received from a cooperating farmer on the following pages. The two fields, comprising 350 acres, were planted from aircraft--field 5 on May 20, 1973 and field 6 on May 15, 1973. Note progress of rice crop growth on following photos and compare these with ERTS-1 images.



Color IR U-2 Support Photo
May 12, 1973

Figure 44. Fields are being flooded prior to planting. Field 5 was planted on May 20 and field 6 on May 15.

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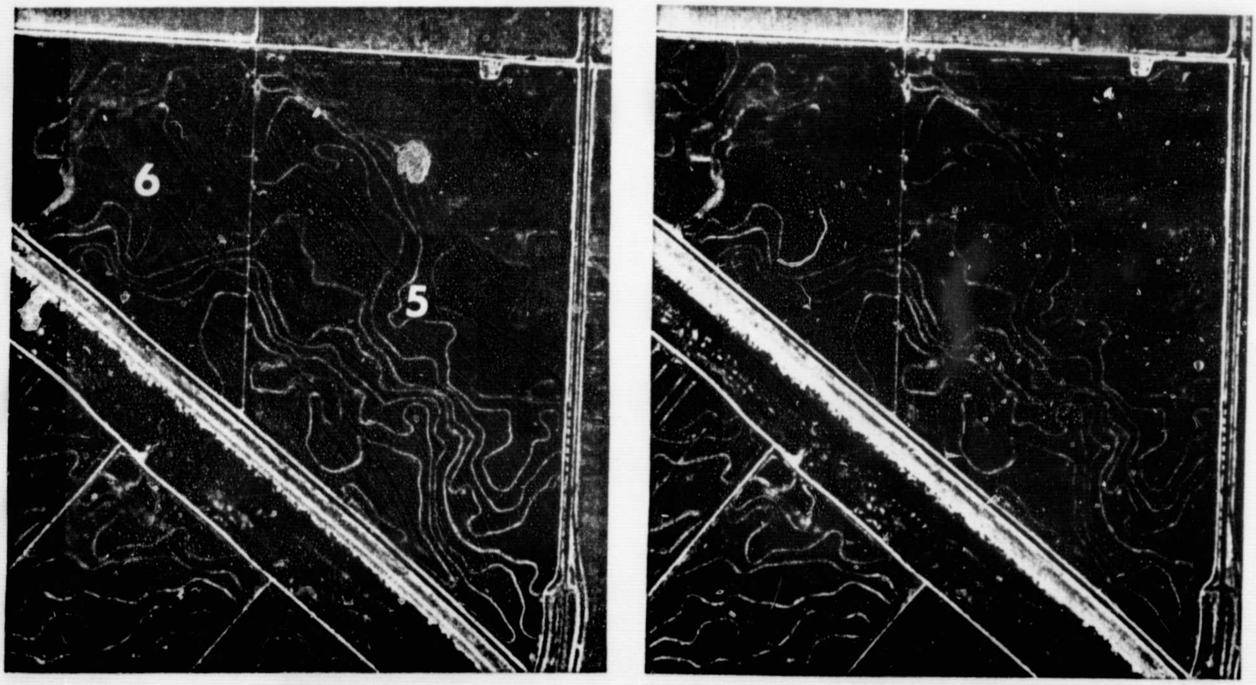
Color IR U-2 Support Photo
July 5, 1973

Figure 45. Rice crop has fully covered water in this photo and some areas of poor stand are visible. Scale 1:42,000.



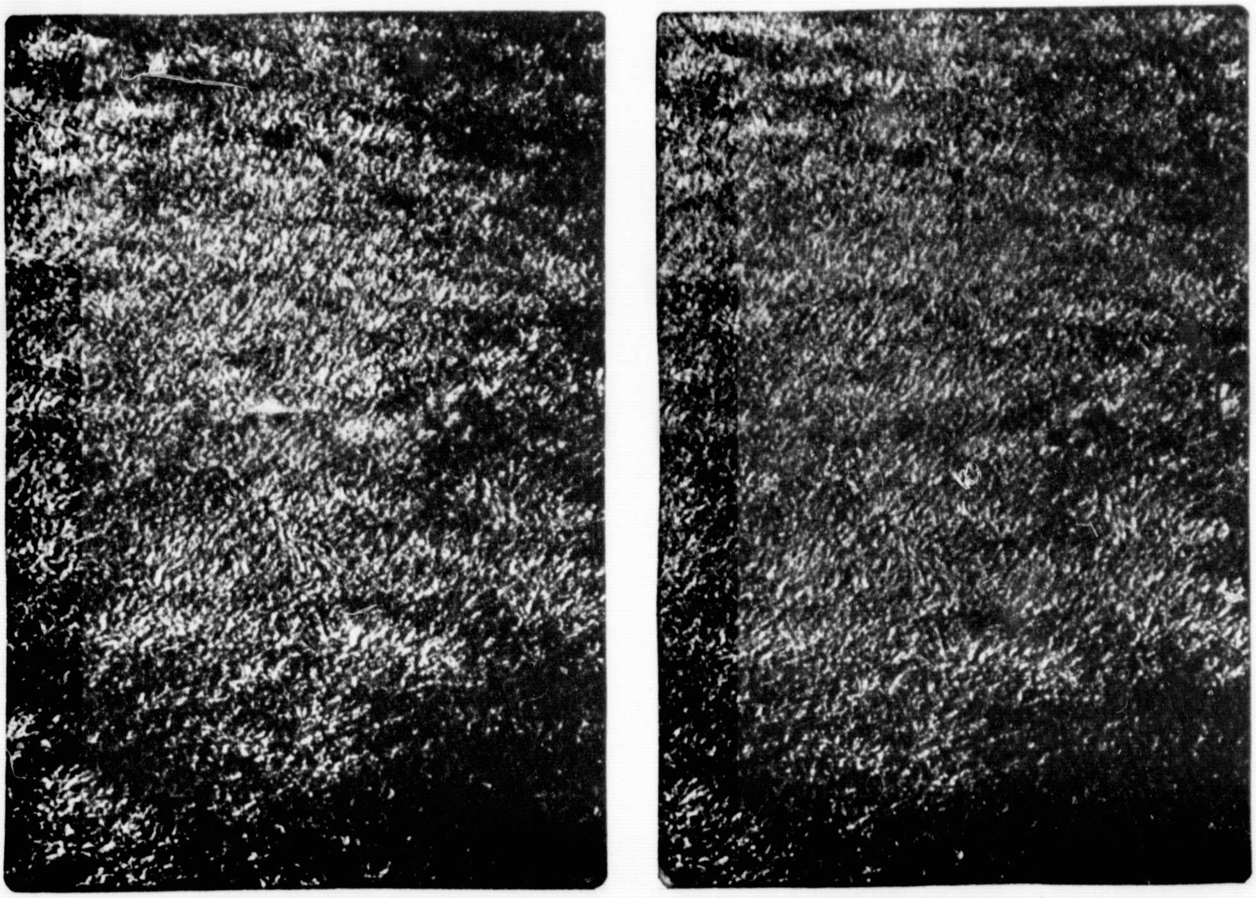
Color

Color IR

Hasselblad Aerial Photos, July 10, 1973

Figure 46. Weed invasion is visible along upper right edge of field at arrow as evidenced by color contrast with rice. Areas of poor stand are also visible. Data sheets from farmer indicated a weed problem. This period (pre-heading) in growth is a critical time for photo coverage. Scale 1:40,000.

Figure 47. Ground view of weed infestation in rice field in California. Weeds in this field seriously reduce yield and lower quality of rice. Color photo, August 1, 1973. No. Great Valley.



Color

Color Infrared

Figure 48. Typical appearance of weed infestation as a result of early heading and maturing of weeds. Weed infestation seriously reduces yield and because of contamination of rice by weeds crop value is reduced. Vertical photos, August 28, 1973. No. Great Valley.

Color

Color Infrared

Figure 49. Ground view of green headed rice that has lodged. Note heavy mass of leaf and head parts of plants indicating susceptibility to lodging. July 26, 1973. No. Great Valley.

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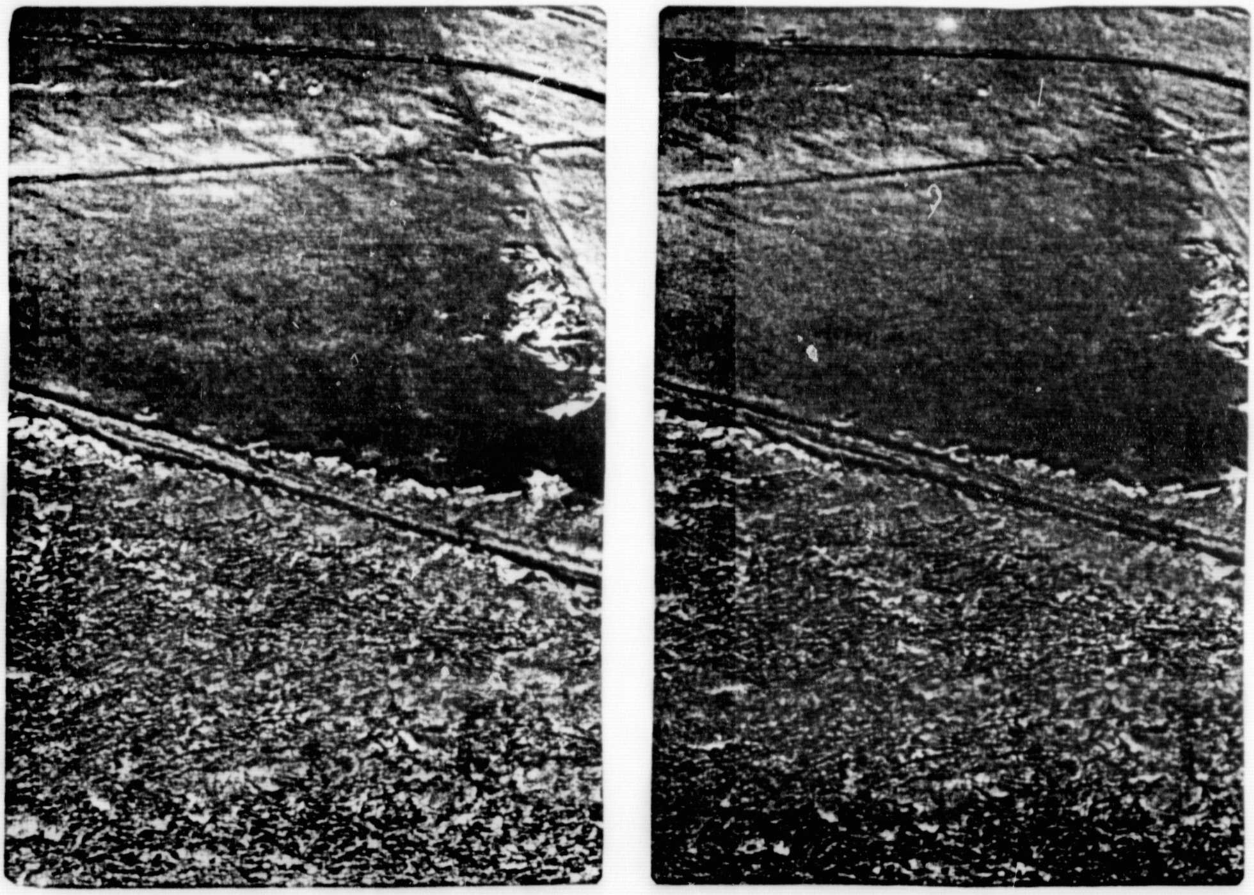
Color

Color Infrared

Figure 50. Drainage problems have resulted in damage to rice stand in a field in California. Absence of rice plants causes a 100% loss in yield in the area affected. Note presence of minor weed infestation to the left of drain as expressed by yellow vegetation in the color image and blue-grey image on the color infrared. Vertical photos, August 28, 1973. No. Great Valley.



Color

Color Infrared

Figure 51. In foreground can be seen green headed rice that has lodged, seriously retarding filling of rice kernels. In background is a weed infested area as evidence by yellow headed and mature weeds. The absence of growing rice plants in weed areas are visible on color infrared photos, thus indicating serious yield reduction in those areas. Oblique photos, August 28, 1973. No. Great Valley.

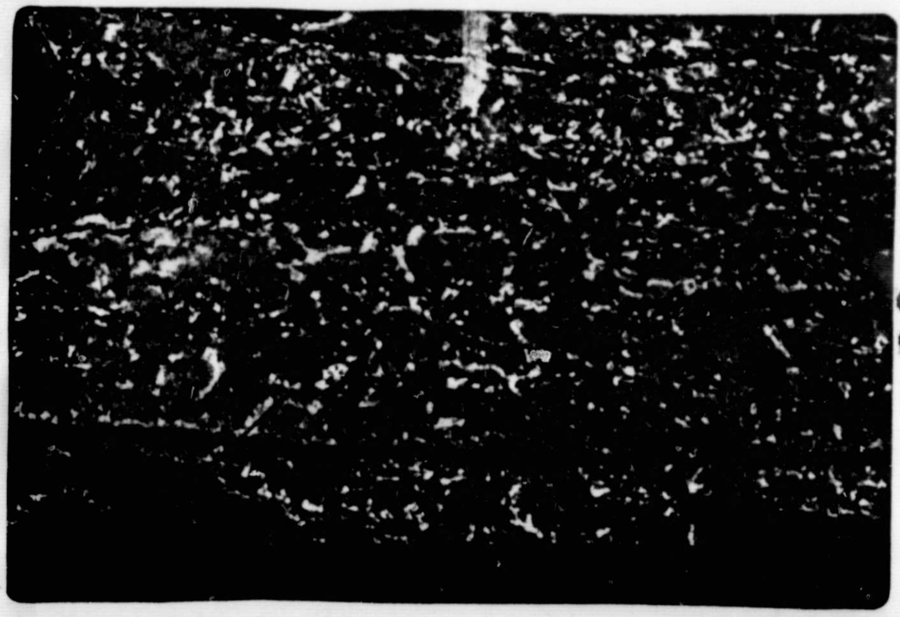


Figure 52. Severe lodging in rice in Louisiana occurred prior to heading and thus causes severe yield reduction in those areas. Note headed rice in lower left where rice is standing. Color vertical photo, August 11, 1973. Louisiana Coastal Plain.

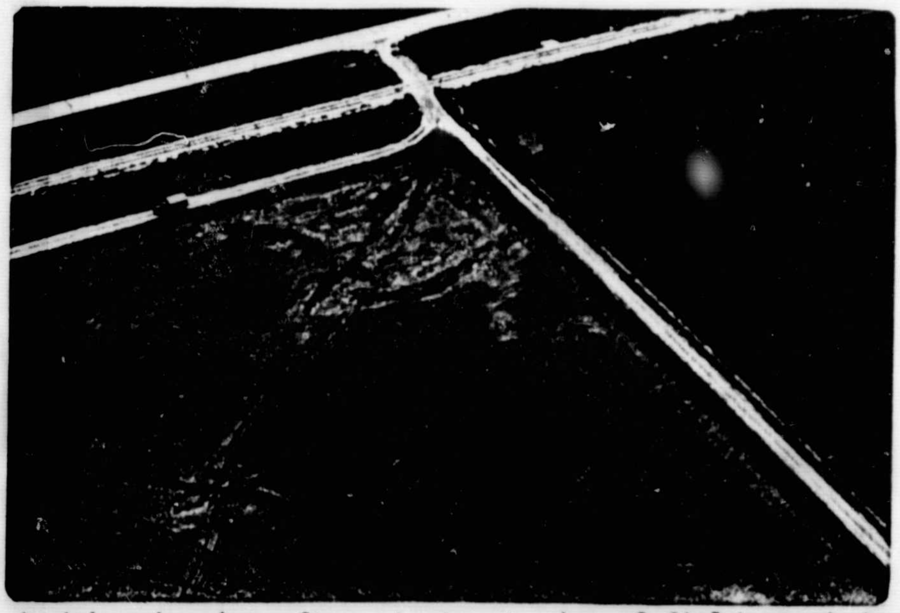


Figure 53. Lodging in rice often starts at edge of field on windward side and spreads as in a "domino" effect. Note almost complete absence of harvestable plants in lodged area caused by early season lodging. Color oblique photo, August 11, 1973. Louisiana Coastal Plain.

Figure 54. Vertical photo of lodged mature rice in Louisiana. Some lodging occurred prior to maturing accounting for the variable appearance of lodged areas. Some loss of yield will result in areas such as these where early lodging occurs. Color vertical photo, August 12, 1973.

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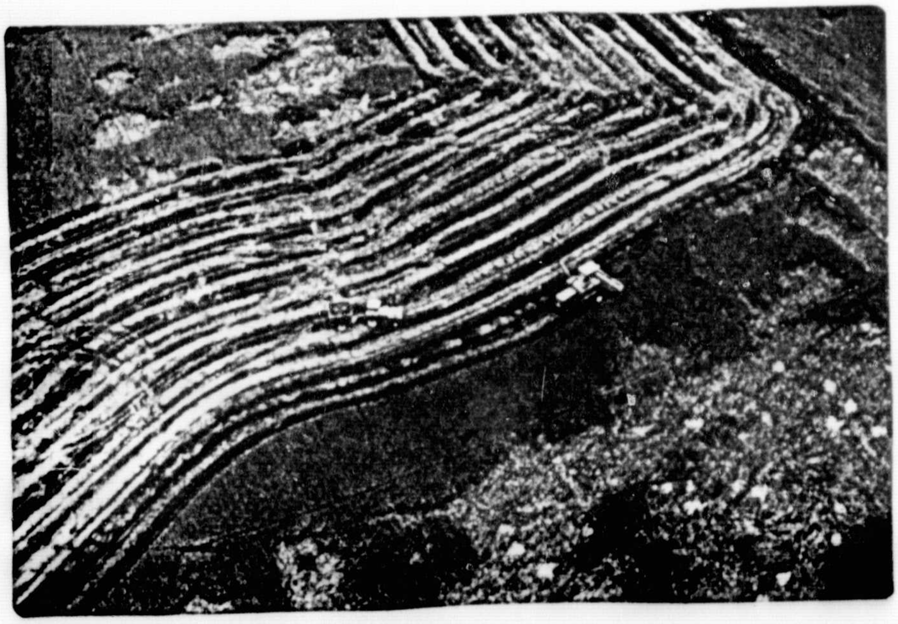
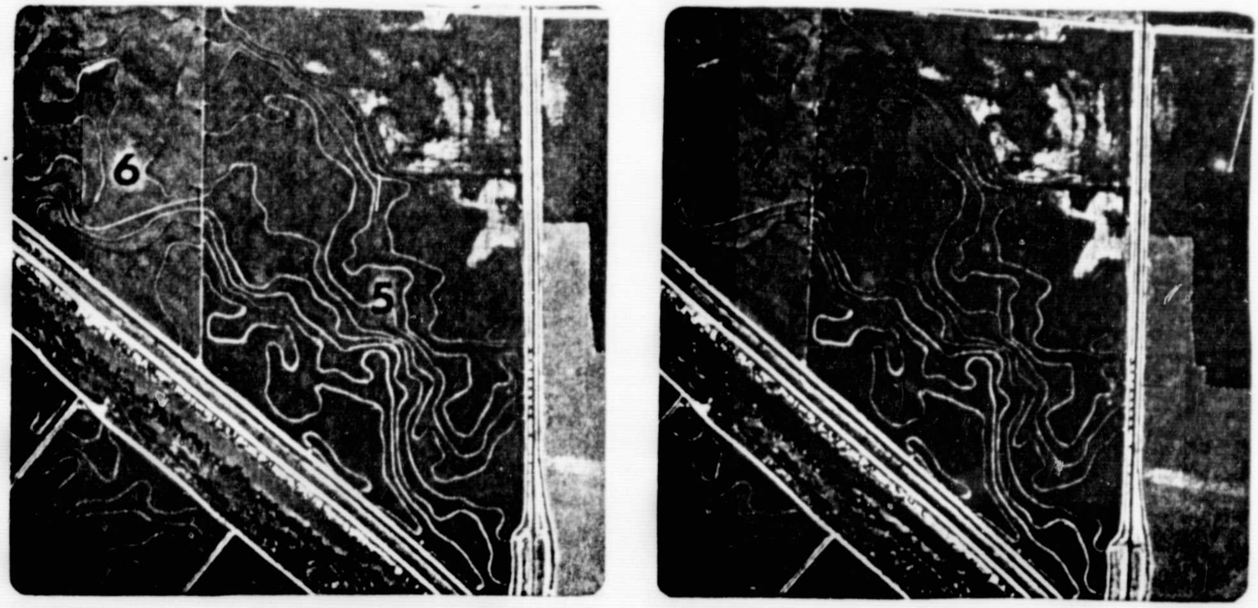


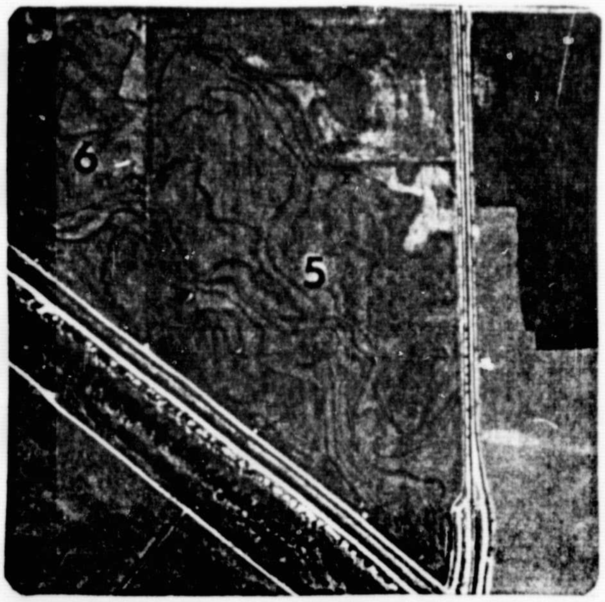
Figure 55. Harvesting of mature rice. Note lodged areas at upper field are still visible after harvesting. Combine is operating at right with a rice hauling unit at left. Color oblique photo, August 11, 1973. Louisiana Coastal Plain.



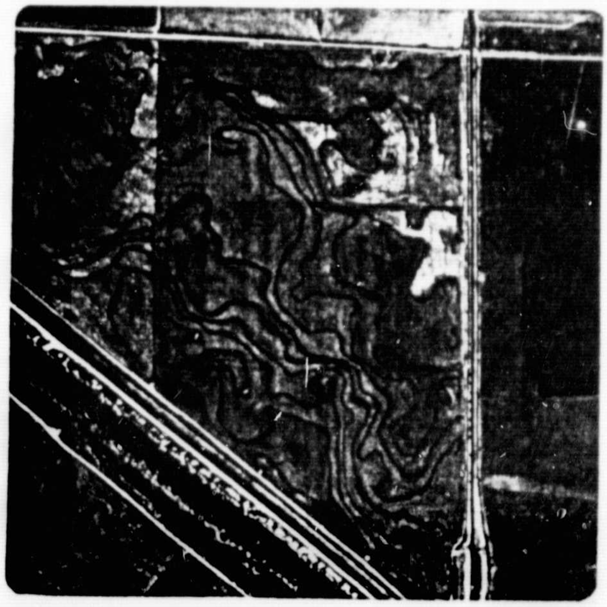
Color | Color IR

Hasselblad Aerial Photos, August 29, 1973

Figure 56. Comparison of photos on this date with those taken on July 10 indicate that the weeds have matured and some of the areas of poor rice stand have disappeared as surrounding vegetation covers gaps. Rice is beginning to head in field at upper left as noted by pinkish color on color IR photo. Scale 1:40,000.



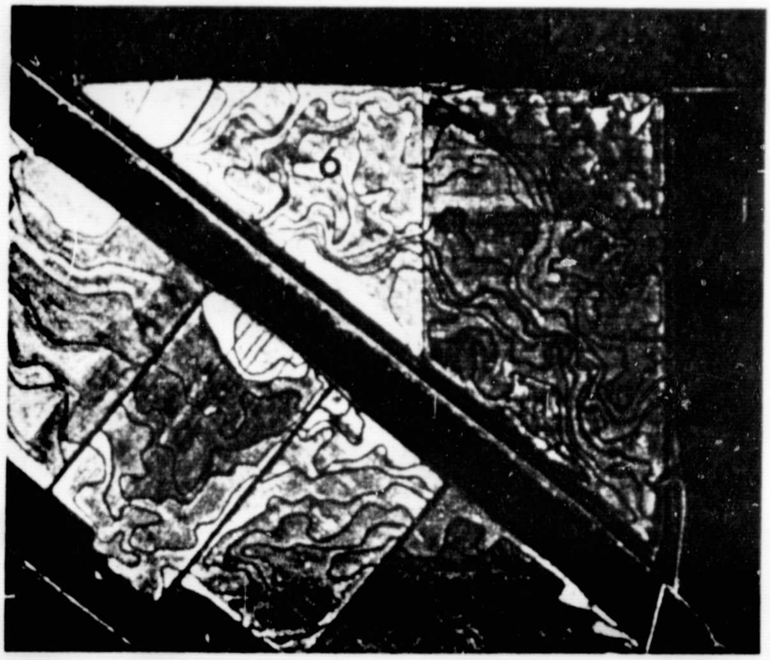
Color



Color IR

Hasselblad Aerial Photos, September 13, 1973

Figure 57. Rice crop is fully headed. Some lodging has occurred in field at upper left. Farmer data sheet for that field (No. 6) indicates that lodging occurred on September 1. Scale 1:42,000.



Color IR U-2 Support Photo
October 10, 1973

Figure 58. Field No. 6 has matured and been harvested on September 30. Stubble is light in tone. Field No. 5 is maturing and was harvested on October 15, 5 days after this photo was taken. According to the farmer, yield on both fields was 5,200 lbs. per acre.

Figure 59. Rice fields of differing maturity cause color contrast in this photo. Field at left has taken on a yellow-green cast, indicating a more mature stand. Color oblique photo. September 13, 1973. No. Great Valley.

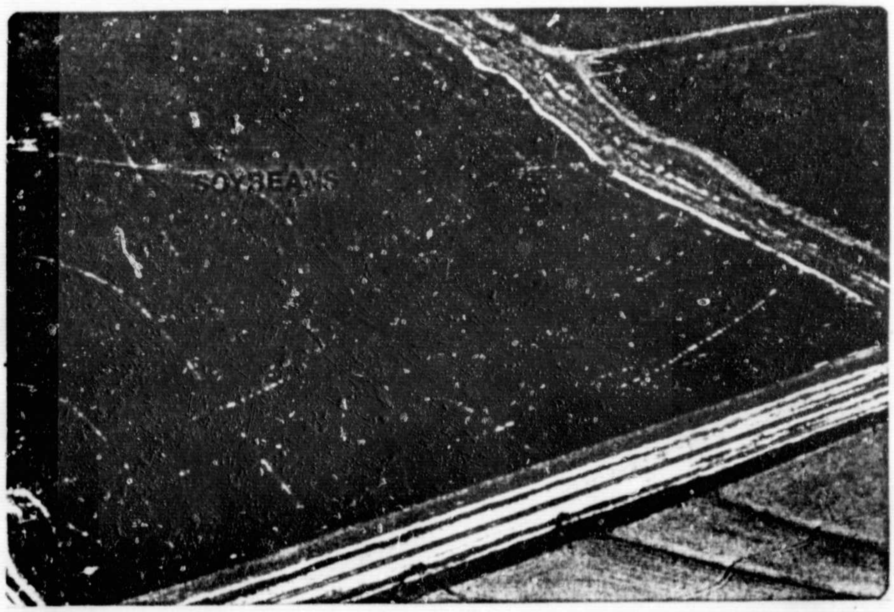


Figure 60. Soybean crop in Louisiana contrasts with rice fields in color and method of culture. Note remnant levees in field from previous rice crop. Note mature rice field at lower right. Color oblique photo, August 12, 1973. Louisiana Coastal Plain.

(e) For estimating weed infestation damage: 60 to 100 days after planting

(f) For estimating wind lodging damage: 90 days after planting to harvest

(g) For determining time of heading: depends upon variety (generally 75 to 100 days after planting)

(h) For making the final pre-harvest analysis: one to two weeks before harvest.

15.6.9 RESULTS OF PHOTO INTERPRETATION TESTS FOR VEGETATION COMPLEX IDENTIFICATION[1]

A series of photo interpretation tests was conducted to compare the results obtained using several image types from ERTS-1 MSS and Skylab EREP systems. The evaluation was based on these test films' usefulness for identifying land use and agricultural crops, and for assessing crop condition and vigor, all factors necessary for yield estimation. The following sections define the results of the previously cited photo interpretation tests using 40 photo interpreters responding to prepared test materials.

[1] A Comparison of Skylab and ERTS Data for Agricultural and Natural Vegetation Interpretation Technical Report, July 1, 1974. Earth Satellite Corporation. Contract No. NAS 9-13286.

15.6.9.1 Agricultural Crops

Crop Identification--Late Summer Seasonal State

For the identification of agricultural crops at the late summer seasonal state, the EREP S-190A color IR and the ERTS color composite images were significantly different from (and better than) all the other image types. For the test area studied, the spectral differentiation afforded by the color infrared medium is more useful for crop type discrimination than is the sharper resolution of the EREP S-190A and S-190B color images. Since all agricultural fields selected as test and training examples were well above the minimum detectable field size, little added information regarding crop type was derived from sharper image detail. For this reason ERTS imagery was essentially as useful in all bands, and in color combinations, as the EREP counterpart. This fact is considered of great importance in the context of the present study because of the potentially greater speed, after acquisition, with which the ERTS imagery can be made available to the analyst.

All four color images ranked higher than the black-and-white images for crop identification. Image ranking is summarized below:

Image Type	Overall Average Correct Responses (all crop categories)[1]
EREP S-190A Color IR	7.5
ERTS Color Composite	7.4
EREP S-190B Color	6.8
EREP S-190A Color	6.7
EREP S-190A B/W IR	6.6
ERTS Band 7	6.4
EREP S-190A B/W Red	6.0
ERTS Band 5	5.5

[1] Maximum possible = 10

Crop Identification--Late Spring Seasonal State

The EREP S-190A color and color IR images again were significantly better than the other image types for crop identification at the late spring seasonal state. All three color images ranked higher than the black-and-white images. Image ranking is summarized below:

Image Type	Overall Average Correct Responses (all crop categories)[1]
EREP S-190A Color	7.1
EREP S-190A Color IR	7.0
ERTS Color Composite	6.1
ERTS Band 5	5.9
EREP S-190A B/W Red	5.8
ERTS Band 7	5.6
EREP S-190A B/W IR	5.4

Crop Identification--Seasonal Comparisons

Overall interpretation results for both image dates were very similar; only for the identification of specific crops can one date be recommended over another. (While not investigated by formal testing, it is probable that multidate imagery would permit more accurate crop identification to be made than would be possible on single date imagery.)

In both cases, all the color images ranked higher as a group than the black-and-white images. For the late summer seasonal state, the EREP S-190A color IR and ERTS color composite were better than the other types; for the late spring seasonal state, the EREP S-190A color IR and color images were best. The numerical rankings of the remaining images were not

[1] Maximum possible = 10.

significantly different; hence, it is impractical to attempt to specify a composite ranking for interpretation at the two seasonal states.

The utility of additive color enhancement techniques for displaying (1) the regional extent of, and (2) changes in areas devoted to rice culture over a two-year period was demonstrated with ERTS imagery.

Land Use Identification and Delineation

The combination of high resolution and spectral discrimination afforded by the EREP color images results in the highest subjective estimate of accuracy for land use identification and delineation. Whereas crop identification *per se* is accomplished most accurately on color infrared (EREP) or color infrared simulations (ERTS), the identification of land use categories frequently depends upon the detection of image pattern or detail as well as a unique image signature (e.g., urban areas are characterized by regular street patterns, and dryland pasture has a unique texture and pattern). Ranking of image type according to total certainty ranking is as follows, best image appearing first:

Image Type	Total Certainty Ranking[1]
EREP S-190B Color	8
EREP S-190A Color	11
EREP S-190A Color IR	14
ERTS Color Composite	15
EREP S-190A B/W Red	16
EREP S-190A B/W IR	19
ERTS Band 7	20
ERTS Band 5	22

[1] 6 = Certain ranking for all categories.

15.6.9.2 Combined Ranking for Agricultural Crop and Natural Vegetation Identification

All eight image types tested have been ranked according to the overall mean correct identification. The ranking of each image type was identical on both tests with one exception (from best to worst):[1]

EREP S-190A Color IR
ERTS Color Composite
EREP S-190B Color
EREP S-190A Color
EREP S-190A B/W IR
ERTS Band 7
EREP S-190A Red
ERTS Band 5

These results indicate that, for the vegetation complexes interpreted, and for the relatively large areas occupied by each test item, the spectral information from a color infrared image or ERTS color infrared simulation is more valuable than increased resolution provided by EREP color (S-190A and S-190B) images.

15.6.10 RESULTS OF PHOTO INTERPRETATION TESTS FOR VEGETATION COMPLEX IDENTIFICATION

15.6.10.1 Agricultural Crops

Minimum Field Size

Minimum field size consistently detectable is directly related to image resolution for targets of both high and low contrast. The image

[1] The EREP S-190A color image ranked lower for natural vegetation than for agricultural crops. However, it was predicted that the poor color quality of the test print (only for the Colorado Plateau Test Area) might affect its interpretability for natural vegetation types. Its composite ranking here is assigned on the basis of the agricultural crop test results only.

types can be ranked as follows (no statistical significance associated with order):

Image Type	Minimum Field Size (Acres) High Contrast	Low Contrast
EREP S-190B Color (high res.)	3-5	5-8
EREP S-190A Color	3-5	5-8
EREP S-190A B/W Red	3-5	5-10
EREP S-190A Color IR	8-12	12-17
EREP S-190A B/W IR	8-12	30-40
ERTS Color Composite	10-15	20-30
ERTS Band 5	10-20	30-40
ERTS Band 7	10-20	30-40

Rice Crop Delineation

Both the ERTS color composite and EREP S-190A color IR images produced highly accurate delineations of a rice growing region. Commission errors were also minimal, indicating that the early summer season is an appropriate time of year for separating rice growing from non-rice growing areas. Using the ERTS color composite, 90.7 percent of the rice growing area was correctly identified; the accuracy obtained with the EREP S-190A color IR image was 82.1 percent.

15.6.11 RESULTS OF PHOTO INTERPRETATION TESTS FOR EVALUATING VEGETATION VIGOR AND CONDITION OF AGRICULTURAL CROPS

Either of the systems tested, EREP or ERTS, has adequate spatial resolution for regional agricultural crop survey purposes. Such surveys usually do not require absolute identification of the crop type in every field throughout the region. In this regard, the value of ERTS for making year-to-year comparisons of regional drought patterns was clearly stated with an example from Young County, Texas. Distinct regional

image signatures were displayed (Figure 42) for drought (1974) and normal (1973) conditions.

For more detailed agricultural surveys, however, such as those used by farm managers, market analysts and tax assessment officials, ERTS data do not provide adequate image spatial resolution for such uses.

EREP S-190A will provide adequate images for some management applications but, as with ERTS images, usually not those requiring local decisions related to plant vigor and stress, such as weed and pest control or soil additives (nitrogen, minerals, etc.).

EREP S-190B, on the other hand, provides improved resolution over the other systems and, when used under favorable atmospheric conditions (clear skies, minimum haze), can be applied by farm managers to make on-site decisions regarding field practices, particularly for fields of five acres or larger in size.

The high resolution afforded by a system such as the EREP S-190B camera is essential for detection of such yield-reducing factors as lodging which have sharp, well-defined boundaries and contrast sharply with the surroundings. Lodging patterns could be frequently confirmed only on the EREP S-190B color image. The high spatial resolution of this system is much more critical for lodging recognition than is the spectral detail of the particular film type used in it. In no cases was it possible to detect lodged rice fields on ERTS imagery because of the relatively poorer spatial resolution.

Because color infrared images provided the most useful data in this study for crop identification and evaluation, it is recommended that color infrared film (or the bands that comprise that film as in ERTS-1) be

specified for systems such as the EREP S-190B or the ERTS MSS when used for crop monitoring applications. This recommendation is justified even though only color film from the S-190B system was available for testing in this study.

The frequency of timing of coverage for regional crop surveys and farm management practices is difficult to specify precisely because of the uncertainty of the occurrence of certain critical environmental events which may alter an otherwise "normal" season. These factors include such events as drought, frost damage, excessive precipitation, and wind storms. As noted earlier, some agricultural areas are more prone to unfavorable weather conditions for remote sensing coverage and thus may be difficult to cover with any inflexible schedule. One factor is certain, however, and that relates to the delay in receipt of images once they have been exposed. For regional surveys, a delay of several weeks may be acceptable to the agricultural analyst. For the market analyst and the farm manager, remote sensing images are a perishable item and a delay of more than a few days can render the images almost useless for making current management decisions because of the irreversibility of some crop problems if action to counteract a faulty condition is not taken promptly.

Experience with both ERTS and EREP by the investigators indicates that data from both systems were not available in time to be applicable to market analysis or farm management and only marginally useful for regional agricultural analysis. In the future, however, it should be possible to make available promptly to the image analyst, (i.e., on a near real-time basis), ERTS-1 data of those agricultural areas that are of greatest interest to him even though this ordinarily would not be possible for EREP-type data.

15.6.12 IMAGE QUALITY CONSIDERATIONS

Usually image analysis, as performed by humans rather than machines, is done from a study of opaque prints, either color or black-and-white. In such instances the photo quality of the prints can significantly affect the interpretability of many features, particularly where tonal contrasts and feature sizes are at or near the threshold of detectability. It is, therefore, important to produce photos for visual interpretation with great care and to ensure that information is not lost in the photo reproduction phase to any significant degree.

Multidate images can provide improved detectability of vegetation types by exploiting the differences in target reflectances as seasonal changes occur (crop calendar characteristics). However, the photo systems tested did not show any inter-system differences in usefulness for the problems studied related to the multidate approach although we only evaluated two dates of Skylab data and seven dates of ERTS imagery for this determination.

15.7 UNRESOLVED PROBLEMS

Time and funds were not available for this project to permit complete and intensive evaluation of all images for use in yield analysis. The factors which have been shown in past studies to be necessary for evaluating yield potential of rice crops were studied and the suitability of the several image types available were analyzed.

In some cases the relative usefulness of a particular image for a particular application was determined by photo interpretation tests, and in other cases specific judgments were made of photo interpretation methods

by remote sensing experts. Where appropriate these findings were reported in the report.

In order for a final evaluation to be made regarding the usefulness of each image type, spectral band and date of photography (e.g, for rice-yield analysis and for specific parcels), considerably more photo interpretation time would be required. From the data that were evaluated, it was apparent that a combination of image types (multiband, multidate, multistage, multi-enhanced, etc.) would provide more information of the types dealt with in this study than could be obtained from any one type.

With reference specifically to spacecraft systems, the following list indicates the unique combination of factors applying to the ERTS-1 system. Since no other spacecraft system offers this highly useful combination of factors, it is our conclusion that the ERTS-type system is the best that has yet been devised for acquiring information of the types dealt with in our present study.

We were not able to make the kind of quantitative, interregional analog comparisons that we had hoped to do. A number of logistic and technologic difficulties contributed to this problem. Color saturation variability in products received from GSFC was too great for precise work even in adjacent frames from the same orbital pass. We ordered color reproductions and enlargements both from Sioux Falls and from the USDA Photo Lab in Salt Lake City in an attempt to overcome the color image delivery and quality problems, but because these could not be ordered at one time from the same laboratory, color quality was not consistent enough to justify quantitative comparisons beyond the aforementioned transmittance measurement.

VALUABLE CHARACTERISTICS OF ERTS DATA IN RELATION TO

THE INVENTORY AND MONITORING OF EARTH RESOURCES

(No other vehicle provides this important combination of characteristics.)

1. Multispectral Capability

   A. Senses for the optimum wavelength bands for use in the inventory and monitoring of most types of earth resources (timber, forage, agricultural crops, minerals, water, atmospheric and oceanographic resources).

   B. Provides high spectral fidelity within each of these bands.

2. Multi-temporal capability (provides multiple "looks" for monitoring seasonal changes in vegetation, rate and direction of plant succession and the accumulation or receding of snow or flood waters).

3. Constant repetitive observation point (facilitates change detection by matching of multi-temporal images).

4. Sun synchronous (nearly constant sun angle) ensures nearly uniform lighting and uniform image tone or color characteristics for use in feature identification.

5. Narrow angular field of sensors (570-mile altitude and only 115-mile swath width avoids tone or color "fall off" at edges of swath and thus increases still further the uniformity of image tone or color characteristics).

6. Provides computer-compatible products directly (facilitates automatic data processing).

7. Potential minimum delay in data availability to user (permits "real-time" analysis and facilitates making globally uniform resource inventories, when appropriate, or analyzing troubled areas such as Sahel, in Africa).

8. Systematic coverage of entire earth except for near-polar regions.

9. Capability for receiving data from ground-based data platforms (facilitates use of "ground truth" data in the inventory and monitoring of earth resources).

10. Spatial resolution is optimum for "first-stage" look and is politically palatable, both domestically and internationally.

11. Data routinely placed in public domain for benefit of all mankind.

The best products we had to work with were produced on our own I^2S color combiner, but by the time various avenues had been explored, remaining funds did not permit the making of quantitative tests. In lieu thereof, experienced interpreters have made subjective evaluations and judgments as to the interregional interpretability of selected sets of analogs and a few of the interregional signatured are illustrated.

16.0 SUMMARY

In summary, our experience indicates that the vegetation analog concept is valid; that depending on the kind of vegetation and its density, analogs are interpretable at different levels in the hierarchical classification from second to the fourth level. The second level uses physiognomic growth form-structural criteria, and the fourth level uses floristic or taxonomic criteria, usually at generic level. Finally, it is our opinion that further work of this nature is justified, but that the analog comparisons should be made in relatively small test areas where large homogeneous examples can be found of each analog. While these test areas should be located by visual examination of carefully prepared color products, the actual comparative testing and signature documentation should be done by digital image analysis rather than by visual color comparisions, as we attempted to do.

Knowing what to expect, i.e., having adequate ground knowledge of the scene areas under study, a universal requirement for detailed image interpretation by ocular methods, the human interpreter can read many kinds of convergent and associated evidence to reach a decision. He can compensate in his judgment for variations in color qualities by placing reliance on relative color values as supported by landform relationships, zonational patterns evident in the scene, and by other vegetation signatures in juxtaposition with the delineation under consideration. In these ways correct interregional decisions on image recognition or identification can be made in spite of the image quality and consistency problem.

As the difficulty of the decision increases, however, the interpreter is forced to move up the legend classification hierarchy to progressively larger and larger more generalized classes to find the point of analogy and thus of interregional identifiability. As this occurs, the information derived has progressively less value for management or local decisions. Its values at the more generalized first, second, and even third levels are mainly in support of broad policy, goal, and resource allocation or land use decisions at the county, regional or national levels. One can reach a point where the derived information produces little or no more information than was already contained in maps and reports on regional plant geography and environmental conditions, except for the fact that ERTS imagery nearly always enables one to improve the accuracy of boundary delineations at each appropriate intensity of mapping. The outstanding exception is, of course, in many developing nations where practically any information mapped with reasonable accuracy, and especially with the pictorial presentation possible with ERTS, is new and highly valuable information.

17.0 AUTHOR IDENTIFIED SIGNIFICANT RESULTS

17.1 NATURAL VEGETATION ANALOG STUDIES

a. The determination of days after snowmelt from ERTS imagery with interpretation in relation to elevation has been found useful in judging equivalence of phenological stage. This helps in selecting imagery dates to minimize a signature variability of natural vegetation analogs when making interregional studies.

b. Our hierarchical legend of analogous vegetational types is continuing to prove useful on an ever widening scope of applications in North America for the interpretation of ERTS as well as aircraft photography, and even into the Middle East. The hierarchical system is ideally suited to a multistage inventory concept and enables one to characterize both vegetational, non-vegetational, and land use features of landscapes in a single, consistent, and highly logical system. With good ground truth knowledge we are finding that we can identify many vegetational analogs at the fourth hierarchical level in the legend system. This is the level at which floristic features are first brought into consideration. The first three levels are based on broad physiognomic and structural characteristics of the vegetation. The fourth level begins to recognize the dominant taxa at generic or quasi-generic level.

c. Limited work with digital data analysis shows the analytical capability to discriminate shrub steppe types at specific plant community or vegetation/soil system levels where the training

sets can be selected and located on the basis of prior synecological research or knowledge. We were able to identify and map sagebrush-bitterbrush communities and two different sagebrush-grass communities where the main difference was the density of sagebrush and grass as related to stony and non-stony soil conditions. This suggests that with further research and development it may be possible to derive information about rangeland resources from the ERTS digital system, that is, at the mapping intensity needed for many management level decisions. Whether or not it will be totally cost-effective with large-scale aerial photographic methods is yet to be determined.

d. As an approach to the quantification of ERTS imagery, transmittances were measured from the Band 5 and 7 black-and-white 9 x 9-inch products. The raw transmittance values, particularly interregionally, were not as useful as band ratios. We calculated transmittance ratios as the quotient of Band 7 - Band 5 by Band 7 + Band 5. Of four analogs compared, aspen and sedge meadow analogs, as a set, are well differentiated from riparian cottonwood and pinyon-juniper analogs as a second set. With refinement of the technique by selecting more suitable dates, there is a strong possibility that the individual members of each set may have uniquely different band ratios and thus be quantitatively separable by this statistical method.

e. Stereoscopic interpretation of ERTS images in the side-lap area seems to improve significantly identification accuracy and productivity by experienced and especially capable interpreters.

f. In each of our test regions, Colorado Plateau and Sierra-Lahontan, we conducted mapping comparisons of ERTS interpretation with conventional maps of natural vegetation analogs. Both were mapped at a comparable intensity. In one of the tests, completion of the ERTS map required five man-days, including field time. The comparable agency map required an estimated three man-months; a manpower efficiency ratio of 12:1 in favor of the ERTS. While in this comparison there were large differences between the two maps on an individual type basis, in some cases we were confident the ERTS-determined acreage was the best estimate, and in others the agency map. Differences for the disparity are discussed in the report. When one considers the combination of total type acreage in proportion to project area together with error per type, the average discrepancy for the project areas averaged only 0.32 percent for the Colorado Plateau Test Area and only 1.9 percent for the Sierra-Lahontan. In both cases, the following types were mapped from ERTS within 10 percent or less of the acreage determined by the conventional surveys: coniferous forest; ponds, lakes and reservoirs; Atriplex uplands; and pinyon-juniper woodlands. Sagebrush shrublands were close with errors of 12.5 percent (Colorado Plateau) and 11.4 percent (Sierra-Lahontan).

g. Our comparisons of the ERTS mapping suggests that one can make highly accurate regional vegetation maps by direct interpretation from good quality ERTS color products, preferably at 1:250,000 scale. Obviously, this level of identification by human interpreter from ERTS "photographic products" cannot be achieved in an information vacuum where the interpreter does not know what to expect on the landscape being examined. He obviously must know the ecology of the landscape and draw heavily on convergent and associated evidence in reaching his identification decisions. In both of these comparisons we were particularly encouraged to learn that we could do so well in identifications at the fourth floristic level in our legend system. This means that we were accurately identifying vegetation analogs dominated by a specific generic level taxon, i.e., sagebrush, saltbush, juniper, ponderosa pine. Thus, we refer to this as the first floristic level in our legend system for natural vegetation analogs. Using this kind of stratification as a starting point, multistage sampling with appropriate scales of aircraft data should enable highly accurate determination of acreage and quality parameters of vegetation analogs in regional surveys at county, state and national level.

17.2 RICE ANALOG STUDIES

Conclusions concerning the usefulness of the ERTS-1 system for identifying and evaluating rice crops must be evaluated with the thought that they are not yet supported by extensive quantitative testing. However, these conclusions have been drawn from the evaluations of skilled and

experienced interpreters, knowledgeable both in image interpretation and rice culture. These conclusions are as follows:

a. Interpretability of the ERTS-1 imagery is consistent and predictable. System resolution and image quality allow discrimination of individual fields on the order of 10 to 20 acres, depending on associated feature contrast. For example, individual farmers with no prior photo interpretation experience were able to locate known geographic features and eventually identify their own fields using either ERTS-1 or 1:120,000 aircraft support photography.

b. The ERTS-1 information system, including ERTS-1 aircraft support and large-scale imagery, can be used for providing both regional and local information about rice location and acreage determination and for evaluating physical and physiological factors that indicate yield potential..

c. Accuracy of identification on any single date of ERTS-1 acquisition will be less than that of multidate analysis due to differences in crop calendar, cultural practices used, rice variety, planting date, planting method, water use, fertilization, disease or mechanical problems, etc.

d. It is evident that accuracy of rice field identification will be high using a combination of photographs taken at three specific periods:

    1. At the time soil has been prepared prior to flooding.
    2. At the time fields are flooded.
    3. At the time vegetation is fully visible above water.

Thus, one of the major keys in the phenological progression of rice (crop calendar) which separates it from the other crops is the transition from the totally flooded to the totally vegetated condition.

e. Mapping and acreage determinations made directly from ERTS-1 imagery without the use of supporting aircraft photos is difficult due to spatial resolution and physical field size problems. It is not possible to recognize and delineate most non-cropped areas (drain ditches, roads, storage yards, pumps, etc.) found within rice fields on the ERTS photographic images. If direct mapping and acreage determination are to be accomplished, acreage reduction factors to correct for included, non-cropped area must be determined for each rice growing region. This acreage correction can be made using support aerial photography.

18.0 RECOMMENDATIONS

We feel that the quality of ERTS imagery is sufficiently good and the feasibility of the interregional analog concept sufficiently encouraging that NASA should fund a major effort to document interregional, North American vegetation and environmental analogs in both a top-quality photographic format and in digital data format. Selection of test areas would be based on what is already known of regional plant geography and phytosociology in North America as refined by the aforementioned interpretation of sample ERTS frames chosen from key regions. The digital tape analysis should concentrate not on classification, but on the quantification of the multispectral images of known analogs. They should be defined according to our unified legend system at least to the fourth hierarchical legend level, which corresponds to the highly meaningful first floristic level. The primary and most valuable product from this work would be a developed and organized vegetational and environmental signature bank assembled in a logically organized manner for efficient use according to a consistent legend system.

To aid the people who must ocularly interpret ERTS images, a high-quality set of ERTS image interpretation keys should also be assembled and organized according to our uniform legend. It would probably be feasible to prepare these to the third hierarchical legend level in most cases and, in some instances, even to the fourth level. It is our belief that these interpretation aids could be assembled on a regional basis for broad ecological provinces and indexed for use in a most effective manner.

In both of these instances, the work could be done effectively and entirely from existing ERTS-1 data and spot checked for continuing applicability with small amounts of imagery from LandSat-2 if desired.

As noted in the report, we were not able to perform a simulated operational photo interpretation exercise to predict yield on either the California or Louisiana rice crop test areas. In California, delays in receiving ERTS and high-flight support imagery prevented any real-time evaluation of the imagery for those areas not covered by our support aerial photography. However, in those areas where we have coverage from ERTS-1, high-flight and low-flight support photos, we were able to determine that the factors which must be monitored and quantitatively evaluated for rice-yield estimation are interpretable consistently and predictably. From these observations we make the recommendation that a study be performed in the Northern Great Valley to map the acreage where rice is grown and to estimate the anticipated production by use of sequential photo coverage from ERTS-type systems supported by photos from a high- or low-flight aircraft in a multistage sample scheme.

Furthermore, an investigation should be conducted which utilizes the ERTS digital tapes to generate data by computer readout for such factors as crop identification and acreage determination, and utilizes a combination of visual and computer readout for evaluating plant vigor and stress.

As noted, the coverage received of the Louisiana Coastal Plain test site was not adequate to permit an evaluation of the method devised because of persistent weather problems. It, therefore, is recommended that a study be done to determine what spacing of sequential coverage

would be needed to provide adequate photo coverage (at least once every 18 days) over the Louisiana rice crop areas in a typical year. From these data it would be possible to determine the spacing of satellite overpasses that would be needed in order to assess the rice crop in Louisiana by a sun synchronous satellite system.

APPENDIX A:

The Symbolic and Technical Legend Classes Appropriate to this Investigation with Brief Narrative Descriptions of the Primary Through Tertiary Levels of Classification

Symbolic and Technical Legend Classes

EARTH SURFACE AND LAND USE FEATURES

PRIMARY CLASSES

100 - BARREN LAND
200 - WATER RESOURCES
300 - NATURAL VEGETATION
400 - CULTURAL VEGETATION
500 - AGRICULTURAL PRODUCTION
600 - URBAN, HEAVY/LIGHT INDUSTRY, TRANSPORTATION
700 - EXTRACTIVE INDUSTRY
900 - OBSCURED LAND

SECONDARY CLASSES

100 - BARREN LAND
- 110 - Playas, dry, or intermittent lake basins
- 120 - Aeolian barrens
- 130 - Rocklands
- 140 - Shorelines, beaches, tide flats, and river banks
- 150 - Badlands
- 160 - Slicks
- 170 - Mass movement
- 180 - Man-made barrens, other than extractive industry
- 190 - Undifferentiated complexes of barren lands

200 - WATER RESOURCES
- 210 - Ponds, lakes, and reservoirs
- 220 - Water courses
- 230 - Springs, seeps, and wells
- 240 - Lagoons and bayous
- 250 - Estuaries
- 260 - Bays and coves
- 270 - Oceans, seas, and gulfs
- 280 - Snow and ice
- 290 - Undifferentiated complexes of water resources

300 - NATURAL VEGETATION
- 310 - Herbaceous types
- 320 - Shrub/scrub types
- 330 - Savanna-like types
- 340 - Forest and woodland types
- 390 - Undifferentiated natural vegetation

400 - CULTURAL VEGETATION
- 410 - Cultural herbaceous types
- 420 - Cultural shrub/scrub types
- 430 - Cultural savanna-like types
- 440 - Cultural forest and woodland types
- 490 - Undifferentiated cultural vegetation types

500 - AGRICULTURAL PRODUCTION
- 510 - Field crops
- 520 - Vegetable and truck crops
- 530 - Tree, shrub, and vine crops
- 540 - Pasture
- 550 - Horticultural specialties
- 560 - Non-producing fallow, transitional, or idle land
- 570 - Agricultural production facilities
- 580 - Aquaculture
- 590 - Undifferentiated agricultural production

600 - URBAN AND RESOURCE EXTRACTION
- 610 - Residential
- 620 - Commercial and services
- 630 - Institutional
- 640 - Industrial
- 650 - Transportation, communications, and utilities
- 660 - Resource extraction
- 670 - Open space
- 690 - Undifferentiated urban

700 - EXTRACTIVE INDUSTRY
- 710 - Sand and gravel
- 720 - Rock quarrie
- 730 - Petroleum fields, gas and oil fields
- 740 - Oil shale and sand extraction
- 750 - Coal or peat
- 760 - Non-metallic, chemical, fertilizer, etc.
- 770 - Metallic
- 790 - Undifferentiated extractive industry

900 - OBSCURED LAND
- 910 - Clouds and fog (including cloud shadows)
- 920 - Smoke and haze
- 930 - Dust and sand storms
- 940 - Smog
- 950 - Topographic shadows
- 990 - Undifferentiated obscured land

TERTIARY CLASSES

100 - BARREN LAND

- 110 - Playas, dry or intermittent lake basins
- 120 - Aeolian barrens (other than beaches and beach sand)
  - 121 - Dunes
  - 122 - Sandplains
  - 123 - Blowouts

130 - Rocklands

- 131 - Bedrock outcrops (intrusive & erosion-bared strata)
- 132 - Extrusive igneous (lava flows, pumice, cinder and ash)
- 133 - Gravels, stones, cobbles & boulders (usually transported)
- 134 - Scarps, talus and/or colluvium (system of outcropping strata)
- 135 - Patterned rockland (nets or stripes)

140 - Shore-lines, beaches, tide flats, and river banks
150 - Badlands (barren silts and clays, related metamorphic rocks)
160 - Slicks (saline, alkali, soil structural, non-playa barrens)
170 - Mass movement
180 - Man-made, land fill
190 - Undifferentiated complexes of barren lands

200 - WATER RESOURCES

210 - Ponds, lakes, and reservoirs
- 211 - Natural lakes and ponds
- 212 - Man-made reservoirs and ponds

220 - Water courses
- 221 - Natural water courses
- 222 - Man-made water courses

230-270, and 290 - No tertiary classes to date.

280 - Snow and ice
- 281 - Seasonal snow cover
- 282 - Permanent snow fields and glaciers

300 - NATURAL VEGETATION

310 - Herbaceous types
- 311 - Lichen, cryptogam, and related communities
- 312 - Prominently annuals
- 313 - Forb types
- 314 - Grassland, steppe, and prairie
- 315 - Meadows
- 316 - Graminaceous marshes
- 317 - Tule marshes
- 318 - Bogs
- 319 - Undifferentiated complexes of herbaceous types

320 - Shrub/scrub types
- 321 - Microphyllous, non-thorny scrub
- 322 - Microphyllous thorn scrub
- 323 - Succulent and cactus scrub
- 324 - Halophytic shrub
- 325 - Shrub steppe
- 326 - Sclerophyllous shrub
- 327 - Macrophyllous shrub
- 328 - Microphyllous dwarf shrub
- 329 - Undifferentiated complexes of shrub/scrub types

330 - Savanna-like types
- 331 - Tall shrub/scrub over herb layer
- 332 - Broad-leaved tree over herb layer
- 333 - Coniferous tree over herb layer
- 334 - Mixed tree over herb layer
- 335 - Broad-leaved tree over low shrub layer
- 336 - Coniferous tree over low shrub layer
- 337 - Mixed tree over low shrub layer
- 339 - Undifferentiated complexes of savanna-like types

340 - Forest and woodland types
- 341 - Conifer forests
- 342 - Broadleaf forests
- 343 - Conifer-broadleaf mixed forests and woodlands
- 349 - Undifferentiated complexes of forest and woodland types

390 - Undifferentiated natural vegetation - No tertiary classes to date.

400 - CULTURAL VEGETATION

410 - Cultural herbaceous types
- 411-419 - Tertiary levels duplicate those of NATURAL VEGETATION (300)

420 - Cultural shrub/scrub types
- 421-429 - Tertiary levels duplicate those of NATURAL VEGETATION (300)

430 - Cultural savanna-like types
- 431-437, 439 - Tertiary levels duplicate those of NATURAL VEGETATION

440 - Cultural forest and woodland types
- 441-443, 449 - Tertiary levels duplicate those of NATURAL VEGETATION

490 - Undifferentiated cultural vegetation types - No tertiary classes to date.

500 - AGRICULTURAL PRODUCTION

510 - Field crops
511 - Cereal and grain crops
512 - Forage crops
513 - Sugar crops

These are the main classes with which we were concerned in this investigation. Remaining classes are deleted from this presentation in the interest of brevity. At the quaternary level, the specific kind of crop, rice in our instance, is indicated by an additional digit placed to the right of a decimal point.

MACRORELIEF

1.0 - Flat lands (Prominent slopes $<10\%$)

1.1 - Non-dissected
1.2 - Dissected

2.0 - Moderately undulating to rolling lands (Slopes 10 - 25%)

2.1 - Non-dissected
2.2 - Dissected

3.0 - Hilly lands (Slopes $< 25\%$, $< 1{,}000'$ relief, smooth slopes, simple drainage systems)

4.0 - Mountainous lands (Slopes, relief, and complexity greater than in 3.0)

LANDFORM FEATURES

1.0 - Depressional or wet lands, non-riparian

1.1 - Intertidal zone
1.2 - Swamps and marshes
1.3 - Seasonally ponded basin

2.0 - Bottomlands, riparian

2.1 - Stringer or narrow bottomlands
2.2 - Wide valley bottoms, substantial flood plains
2.3 - Seasonal streambeds and washes

3.0 - Planar surfaces

- 3.1 - Fans and bajadas
- 3.2 - Terraces
- 3.3 - Gently undulating to rolling uplands, plateaus, table-lands and mesas
- 3.4 - Pediments

4.0 - Aeolian featured landscapes

5.0 - Slope Systems (Slope classes according to the following table, class is the one-hundredths 0.0X digit).

Slope Range %	Slope Class Digit
Simple Slope Systems	
0 - 5	.01
5+ - 15	.02
15+ - 30	.03
30+ - 50	.04
50+ -100	.05
<100	.06

Slope Range %	Slope Class Digit
Complex Slope Systems	
0 - 30	.07
15 - 50	.08
30 - 100+	.09

The 0.X digit in each case is reserved for landform feature subclass. The slope classes may be added to any appropriate landform feature class by the notation 0.0X, e.g., 4.03; 6.08; 3.22.

Descriptive Legend for Selected Classes

Primary Classes

100 - BARREN LAND: Barren land is somewhat relative but it is intended to cover all situations where the earth surface is essentially barren, rock, gravel, or mineral soil. It is impossible to specify a vegetational cover percentage threshold for barren land. For example, a talus slope with a few shrubs around the periphery or rarely within the talus would still be a barren land class. Desert vegetation will cause the most problem. If the natural ecosystem in a desert climate is sparsely vegetated, it would fall into one of the desert classes, usually symbol 320, even though total percentage ground cover may be well under 10 percent. The more common barren land classes in the desert scene are desert pavement or gravel cover falling into class 133, playas class 110, badlands 150, or slicks 160. Barren lands in desert environments should be almost completely devoid of any vegetation. Commonly in the desert uplands there are scarps, talus, and colluvia, class 134. To the casual observer, many of these will appear essentially barren but if they support a scattered vegetation uniformly throughout the area of steep desert slopes, they should carry an appropriate 300 class.

200 - WATER RESOURCES: Include all ground surface areas covered by natural or man-made water surfaces--streams, lakes, reservoirs, snow and ice, canals, enclosed aqueducts, and other water bodies lacking a surface vegetational cover. This class includes lakes and ponds with heavy "algal bloom" but not ponds with a floating or moderately dense, emergent vegetational covering.

300 - NATURAL VEGETATION: This class includes natural or native vegetation consisting of essentially indigenous species or introduced species that have become essentially naturalized to the region and that have found an ecological niche as though they were a part of the original vegetation. This class includes all successional stages in the natural vegetation. In mapping and identification, one should avoid trying to map the presumed "climax" or eventual equilibrium vegetation. Map and identify vegetation as it exists at the time imagery was obtained. The postulation of climax areas comes later as an interpretation of the basic inventory.

400 - CULTURAL VEGETATION: This class provides for the culturally introduced and intensively managed vegetations where the management objective is essentially maintenance of a permanent stand subsequently managed and manipulated through ecological rather than agronomic principles. The class is designed primarily to provide for seeded range where the intention is permanency of stand and the planted forest, e.g., grass seedings in a shrub steppe land or savanna land and planted coniferous forests in a hardwood forest area.

Some would argue this class should be in primary category 500, agricultural production. We prefer the class 400 because, generally, foresters and range managers prefer to identify these intensively treated areas as forests and rangeland respectively.

Removal of woody overstory species on potential rangeland, range seedings and clear-cut forests allowed to revert to natural successional patterns are classed in the appropriate 300 category. These types are treated as seral vegetation. If, however, such areas were additionally

planted to exotic species not initially natural to the site, they would then be classed under the appropriate 400, cultural vegetation category.

500 - AGRICULTURAL PRODUCTION: These are land areas cleared of the natural vegetation and managed by agronomic principles for production of food, fiber or fodder crops. The class includes any land areas or structures and facilities directly related to intensive agricultural practices. These agricultural lands are characterized by the relatively constant manipulation by man through control of the vegetation and micro-environment (fertilization, irrigation, etc.).

This class includes the permanent pasture managed for maximum yield by fertilization, irrigation and periodic renovation. These are pastures generally included within or in juxtaposition with the crop field boundary also meeting the above criteria.

Forests or woodland windbreaks and woodlots included within the cropland area would be treated by the appropriate 300 or 400 subclass if the units are of mappable size.

600 - URBAN, HEAVY/LIGHT INDUSTRY, TRANSPORATION: Without a long title, semantics leads to misunderstanding about this class. It includes all urban, residential, light or heavy industrial, and transporation or utilities distribution developments that have modified the natural landscape. The class also includes lands allocated to open space but where man has modified the environment through agronomic, horticultural, or landscaping activities to make it a part of the urban/industrial scene.

Natural areas of mappable size located within urban areas would be treated under the appropriate 300 class. Large areas such as planted forests

or woodlands used incidentally as open space or for screening within the urban/industrial environment should be treated in the appropriate 400, cultural vegetational subclasses.

700 - EXTRACTIVE INDUSTRY: This class covers land spoils, settling basins, processing and milling sites associated with mineral and non-mineral extractive industry, including sand and gravel and coal, peat or petroleum. In some natural environments double symbols may be appropriate where the lands are subjected to two or more uses. For example, a naturally vegetated grassland used for grazing and in which an oil or gas field has also been developed would be characterized by the symbols 310/730. An open pit coal mine with its spoil dumps would obviously carry the single symbol, 750.

900 - OBSCURED LAND: This class is intended to provide for those portions of remotely sensed imagery in which the earth's surface is essentially obscured by clouds and other atmospheric obstruction. It is used primarily where it becomes necessary to account for 100 percent of the image frame area.

Secondary Classes

100 - BARREN LAND: Experience has shown that barren land subclasses should never go beyond tertiary level and frequently it is unnecessary to go beyond the secondary class. To do so makes the barren land class redundant with geological information where the latter is assessed as a component of the physical resource base, environment or land surface features.

Practically all of the secondary classes under 100 are self-explanatory. Problems most frequently arise with class 150 badlands

and class 180 man-made barrens or land fills. Badlands are generally best identified by their intricate drainage patterns and usually irregular slopes and relief although many present a smoothly sloping relief. This class is intended to provide primarily for those barren lands derived from silty and clayey materials or from relatively easily weathered rocks that may produce an intricately grotesque or spire-like series of relief features.

Class 180 should be restricted to man-made land fill and not confused with extractive industry classes that typically generate barren lands, e.g., open pit mining, which fall under class 700 an industrial category.

200 - WATER RESOURCES: These secondary subclasses are all self-explanatory or defined in standard dictionaries. The main divergence of this legend system from others in use is the inclusion of snow and ice, 280, as a sub-category. This seems far more logical to us than separating snow and ice at primary levels as is sometimes done. By inclusion as a subset it permits easy agglomeration of all water resource features in a study area or watershed.

300 - NATURAL VEGETATION:

310 - HERBACEOUS TYPES: That vegetation (annual, biennial, or perennial) which in aspect is dominantly herbaceous--including any or all grasses, grass-like plants, forbs, and non-vascular or vascular cryptogams. Other growth forms of vegetation may be present but they are decidedly subordinate in terms of aspect.

320 - SHRUB/SCRUB TYPES: All types of shrubs are the prominent vegetation. These usually form a closed or nearly closed

layer so that the herbaceous layer is subordinate. The herbaceous ground layer of this vegetation is highly variable but can be important. The aspect is one of a prominently low woody vegetation.

330 - SAVANNA-LIKE TYPES: The world literature in no way agrees on the definition of a savanna. We have thus been somewhat arbitrary in phrasing the following descriptive definition that seems to fit most temperate and many tropical situations where the expression "savanna" has been used to describe the unique community. In contrast to some tropical writers, we are not including the tall grass, sparse overstory with a dense shorter grass understory as savanna. This latter belongs in the 310, herbaceous class. Vegetation consisting of sparse, taller woody plants interspersed somewhat regularly throughout by a more dense low shrub or herbaceous layer to give a distinct two-storied community.

We have tested many percentage cover thresholds in the tall woody layer to differentiate or characterize the savanna. Most of these have been difficult to apply consistently because of variation in the size of the individuals in the tall layer. The larger the size, the more widely they can be dispersed and still present an accurate savanna-like aspect. We therefore prefer not to specify such thresholds but to say that the vegetations should be savanna-like in their appearance or aspect to match as closely as possible the intent of the above description.

340 - FOREST and WOODLAND TYPES: The tree layer forms the dominant vegetational feature. This layer often forms a closed canopy over a variety of subordinate vegetation types.

400 - CULTURAL VEGETATION: The secondary classes for cultural vegetation are the same as those presented above for class 300.

500 - AGRICULTURAL PRODUCTION:

510 - FIELD CROPS: Cereals, grains, forage, drugs, spices, fiber crops and other field crops which are the dominant land use.

520 - VEGETABLE and TRUCK CROPS: Legumes, leafy vegetables, roots, tubers, bulbs, cucurbit, solanaceous, and perennial vegetable crops (including other herbaceous crops such as fruit crops) are in this category.

530 - TREE, SHRUB, and VINE CROPS: Fruit, nut, and beverage crops with tree, shrub, or vine growth forms.

540 - PASTURE: Any intensively managed land (fertilized, irrigated and/or renovated as appropriate) utilized for grazing or browsing, with or without periodic mechanical harvest. A pasture may be harvested as a "permanent" crop or managed as a temporary lay in a crop rotation plan.

550 - HORTICULTURAL SPECIALTIES: Artificially planted and maintained flower, shrub, or tree stock. This includes nursery stock, flowers (whether grown for seed, rootstocks, corns, bulbs, tubers, or blooms), and other herbaceous horticultural plants occurring in various sized production lots.

560 - NON-PRODUCING FALLOW, TRANSITION, or ENTRAPPED LAND: Fallow plowed (or variously worked), and leached cropland including harvested fields; included here are abandoned or idle croplands, fields, and pastures as well as entrapped lands that are isolated from effective agricultural production by being surrounded or blocked from access by class 600 lands.

570 - AGRICULTURAL PRODUCTION FACILITIES: At all but the largest of inventory scales these features usually represent point data, i.e., of non-mappable size, but they may be particularly important to annotate, especially in complete land use inventories. Structures and facilities utilized for animal or plant production (except fisheries, see class 580) make up this category. Barns, sheds, holding pens, and greenhouses are examples.

580 - AQUACULTURE: Fish and shellfish hatcheries or other structures, rearing areas, and production ponds are included in this category.

600 - URBAN, HEAVY/LIGHT INDUSTRY, TRANSPORATION:

610 - RESIDENTIAL: Single and multiple unit dwellings including secondary structures, driveways, and landscaped areas. Sparse residential land use should be treated as point data within that land use or resource class within which they are dispersed.

620 - COMMERCIAL and SERVICES: Areas used predominantly for the sale, storage, and handling of products and services. Suburban and city shopping centers, warehouses, waste disposal areas, office buildings, parking lots, and intensively developed resort sites are examples of this category.

630 - INSTITUTIONAL: Education, religious, health, correctional, and military facilities are the main components of this category. All buildings, grounds, and lots that make up the facility are included here. Areas not specifically related to the purpose of the institution should be placed in the appropriate category.

640 - ACTIVITY CENTERS, and AREAS: Centers of human cultural, artistic, and recreational activities where structures compose the majority of the facility (as opposed to open or landscaped space, see class 680). Land areas may be variously developed by landscaping techniques but the areal extent of the landscaped land is less than the structures utilized in the activity. Opera houses, stadiums, civic centers, theaters, and other activity centers are examples of this category.

650 - INDUSTRIAL: All types of light manufacturing and industrial parks to heavy manufacturing. Light industries concentrate on finishing, assembling, designing, and packaging products while heavy industries require more or less large amounts of raw materials such as metal ores, timber, and other materials. These heavy industry sites are usually associated with concentrations of raw materials, transportation facilities, power sources, and waste products.

660 - TRANSPORTATION, COMMUNICATIONS, AND UTILITIES: Highways and railways make up the two basic transportation means that require stationary routings visible on remote sensing images. Facilities related to all transportation types are included in this category (seaports, airports, runways, railroad terminals, bus terminals, highways, roads, etc.). Resource transportation facilities that are nonmobile themselves are included in this category (oil pipelines, gas, electricity and airwave facilities).

700 - EXTRACTIVE INDUSTRY: The secondary classes in this category are self-evident from the class names, e.g., iron, copper, aluminum.

900 - OBSCURED LAND:

910 - CLOUDS AND FOG: Naturally occuring water vapor obscuring the land surface, including cloud shadows.

920 - SMOKE AND HAZE: Natural or man-caused smoke or haze dense enough to obscure the land surface.

930 - DUST AND SAND STORMS: Sand, silt and/or clay particles bornealoft and dense enough to obscure the land surface.

940 - SMOG: Man-caused particulate matter, vapors, chemicals and other smog substances suspended in the atmosphere densely enough to obscure the land surface.

950 - TOPOGRAPHIC SHADOWS: At low sun angles in regions of high and steep relief, many slopes are shaded to the point that resource and surface features cannot be discerned. This class covers such instances.

Tertiary Classes

310 - HERBACEOUS TYPES:

311 - LICHEN, CRYPTOGAM, and RELATED COMMUNITIES: Areas with lichens, mosses, liverworts, algae, fungi, vascular cryptogams and any other non-woody non-angiospermous plants occurring as the dominant vegetation. This class is primarily used in arctic and alpine tundra conditions. Lichen covered rocklands should be classed 130, not 310.

312 - PROMINENTLY ANNUALS: Areas often devoid of vegetation during much ofthe year with more or less dense annual plants growing during certain seasons of favorable precipitation. This class usually possesses a graminaceous aspect.

313 - FORB TYPES: Biennial or perennial broad-leaved herbs forming the dominant vegetation. This class does not include prominence of grasses, grass-like plants, and vascular cryptogams.

314 - GRASSLAND, STEPPE, and PRAIRIE: Any land area dominated by grass vegetation. Tall grass prairies, short grass prairies, desert grasslands, "midgrass plains," bunchgrass, and grass dominant steppes are all included in this category.

315 - MEADOWS: Areas dominated generally by species of Gramineae (grasses) or Cyperaceae (and related families, sedges and rushes, grass-like) where soil moisture conditions fluctuate greatly from one season to the next but tend toward mesism.

316 - GRAMINACEOUS MARSHES: Hygric (very wet) vegetation dominated by mixtures or dense stands of individual grass species.

317 - TULE MARSHES: Hygric (very wet) vegetation dominated by Juncaceae (rushes), Cyperaceae (sedges), Typhaceae (cattails), or other aquatic and sub-aquatic angiosperms (seed plants).

318 - BOGS: Hygric vegetation dominated by Sphagnum and/or other mosses, cryptogamic or bog inhabiting plants.

320 - SHRUB/SCRUB TYPES:

321 - MICROPHYLLOUS, NON-THORNY SHRUB/SCRUB: Small-leaved, non-thorny, small shrub or scrub species occurring as the dominant overstory vegetation type. Microphyllous desert shrublands are the dominant areas with these vegetation types.

322 - MICROPHYLLOUS THORN SHRUB/SCRUB: Small-leaved, thorny shrub or scrub species occurring as the dominant overstory vegetation. This category includes desert thorn scrub predominantly.

323 - SUCCULENT and CACTUS SCRUB: Cactaceae (cactus), Euphorbiaceae (cactus-like), and other succulent plants occurring as the dominant vegetation type.

324 - HALOPHYTIC SHRUB: Salt tolerant shrubs occurring as the dominant vegetation type predominantly in playas, alkali flats and other soils with high salt contents. This class includes such genera as Atriplex, Eurotia, Gravia, and Sarcobatus.

325 - SHRUB STEPPE: Artemisia, Chrysothamnus, Purshia, Cowania and other shrubs occurring as the dominant vegetation over a subdominant or co-dominant stand of grasses (including some forbs) in the understory.

326 - SCLEROPHYLLOUS SHRUB: Shrublands with leathery-leaved, evergreen species adapted to xeric and mediterranean environments occurring as the dominant vegetation. This category includes chaparral (Quercus, Arctostaphylos, Ceanothus, Cercocarpus) and chamise types (Adenostoma-Salvia).

327 - MACROPHYLLOUS SHRUB: Large-leaved, deciduous shrubs occurring as the dominant vegetation; including Salicales (willows), Rosales (rose), Aceraceae (maple), Shepherdia, Symphoricarpos (snowbush), and some Ericales (heaths).

328 - MICROPHYLLOUS DWARF SHRUB: Small-leaved shrubs forming the dominant vegetation type; including ericaceous arctic and alpine heath vegetation and shrub bogs. This is predominantly an arctic-alpine class.

330 - SAVANNA-LIKE TYPES:

331 - TALL SHRUB/SCRUB OVER HERB LAYER: Tall shrubs and scrubby tree species occurring over a predominantly herbaceous layer

that is co-dominant with or more prominent than the shrub/scrub vegetation.

<u>332 - BROAD-LEAVED TREE OVER HERB LAYER</u>: Evergreen, semi-deciduous, or deciduous angiosperm tree species over herbaceous vegetation.

<u>333 - CONIFEROUS TREE OVER HERB LAYER</u>: Coniferous tree species over herbaceous vegetation.

<u>334 - MIXED TREE OVER HERB LAYER</u>: Coniferous and angiospermous tree species over an herbaceous layer, with either predominating but neither tree type $<$20% cover.

<u>335 - BROAD-LEAVED TREE OVER LOW SHRUB</u>: Evergreen, semi-deciduous, or deciduous angiospermous tree species over low shrub layer.

<u>336 - CONIFEROUS TREE OVER LOW SHRUB</u>: Coniferous tree species over a low shrub layer.

<u>337 - MIXED TREE OVER LOW SHRUB</u>: Coniferous and angiospermous tree species over a low shrub layer, with either predominating but neither tree type $<$20% cover.

<u>340 - FOREST and WOODLAND TYPES</u>:

<u>341 - CONIFER FORESTS</u>: Forested areas of cone-bearing trees dominated ($>$80% cover) by an Coniferales or Taxales.

<u>342 - BROADLEAF FORESTS</u>: Deciduous, semi-deciduous, or evergreen angiospermous (flowering) forest species ($>$80% cover).

<u>343 - CONIFER-BROADLEAF MIXED FOREST and WOODLAND</u>: Any conifers and Taxales and broadleaf angiosperms mixed in a dense forest growth or more open woodlands. Cover of the conifer-broadleaf mixture may vary from 20-80% to 80-20%, respectively.

APPENDIX B

1.0 DETAILED PRESENTATION OF PHOTO INTERPRETATION METHODS FOR ACCURATE YIELD ESTIMATION

1.1 DETECTING CHLOROSIS OF VEGETATION BY AERIAL PHOTOGRAPHY

Vegetation responds to its environment by expressing visible characteristics of growth, color of foliage, shape of plant, production of fruit, and survival or death, depending upon the agents influencing the plant. The agronomist utilizes the appearance of a cereal crop plant to assess the effect of the environment upon the plant and upon its ability to produce a merchantable crop of grain. The photo interpreter utilizes similar symptoms in analyzing aerial and space photography for crop analysis.

1.2 DETECTING DISEASE AND WILTING OF VEGETATION BY AERIAL PHOTOGRAPHY

Certain relationships between foliage and sunlight reflectance should be understood to facilitate detecting diseased and wilted vegetation by aerial photography.

The schematic drawing of a cross-section of a healthy oats leaf (Figure 62) (Colwell, 1956) is presented for illustration of the behavior of sunlight falling on a healthy green leaf. Note that certain wavelengths are largely absorbed, while others are reflected to a high degree, either by the chloroplasts or by the spongy mesophyll tissue. Reflection from the cuticle on the upper surface of a green leaf is relatively minor and, therefore, is not diagrammed. The spectrometric curve for a healthy rice leaf, and a similar curve for a rice leaf in which wilting has been induced, are illustrated in the accompanying diagram (Figure 63). Both curves might have been predicted with

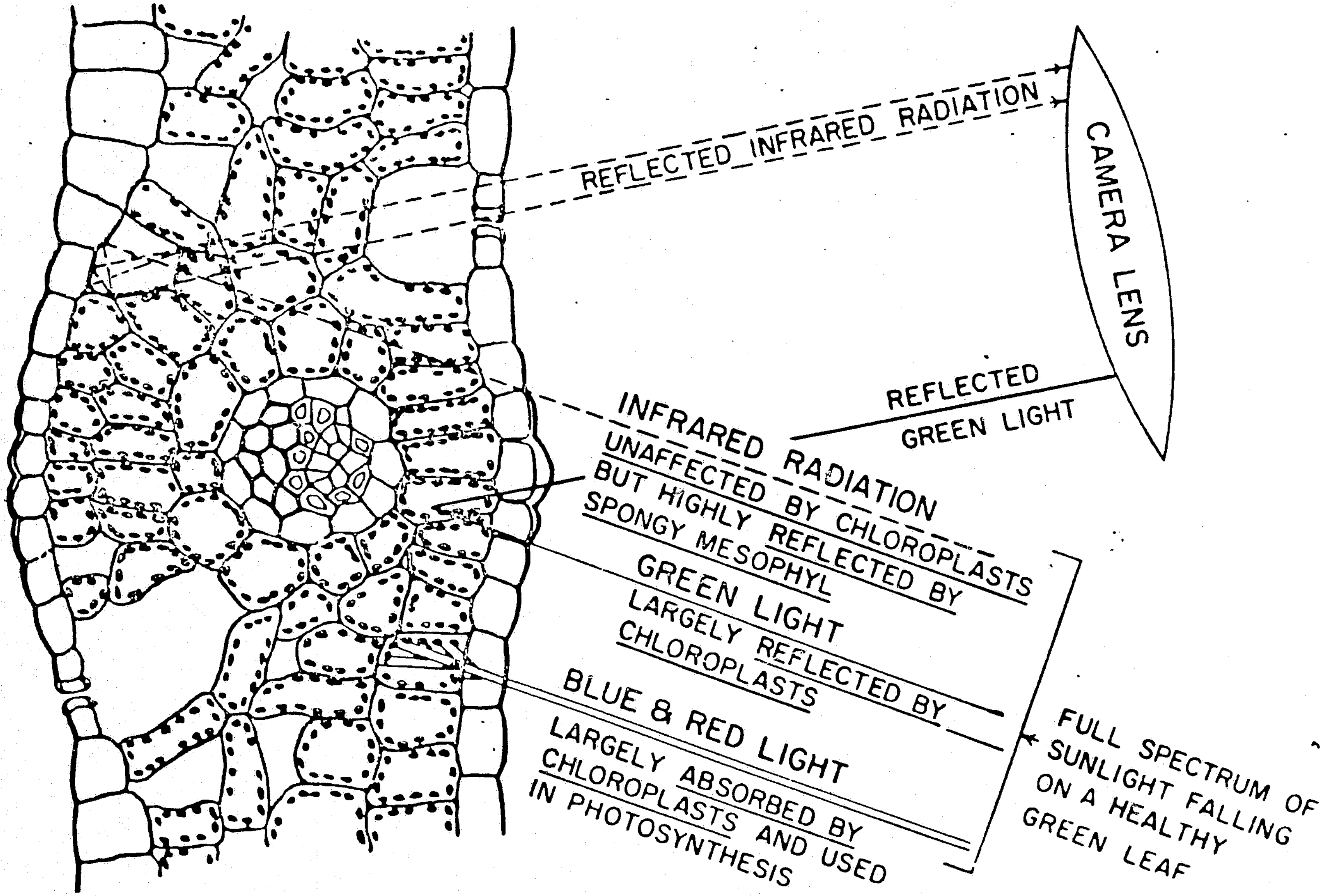


Figure 62. Schematic of a Cross-Section of a Healthy Oats Leaf.

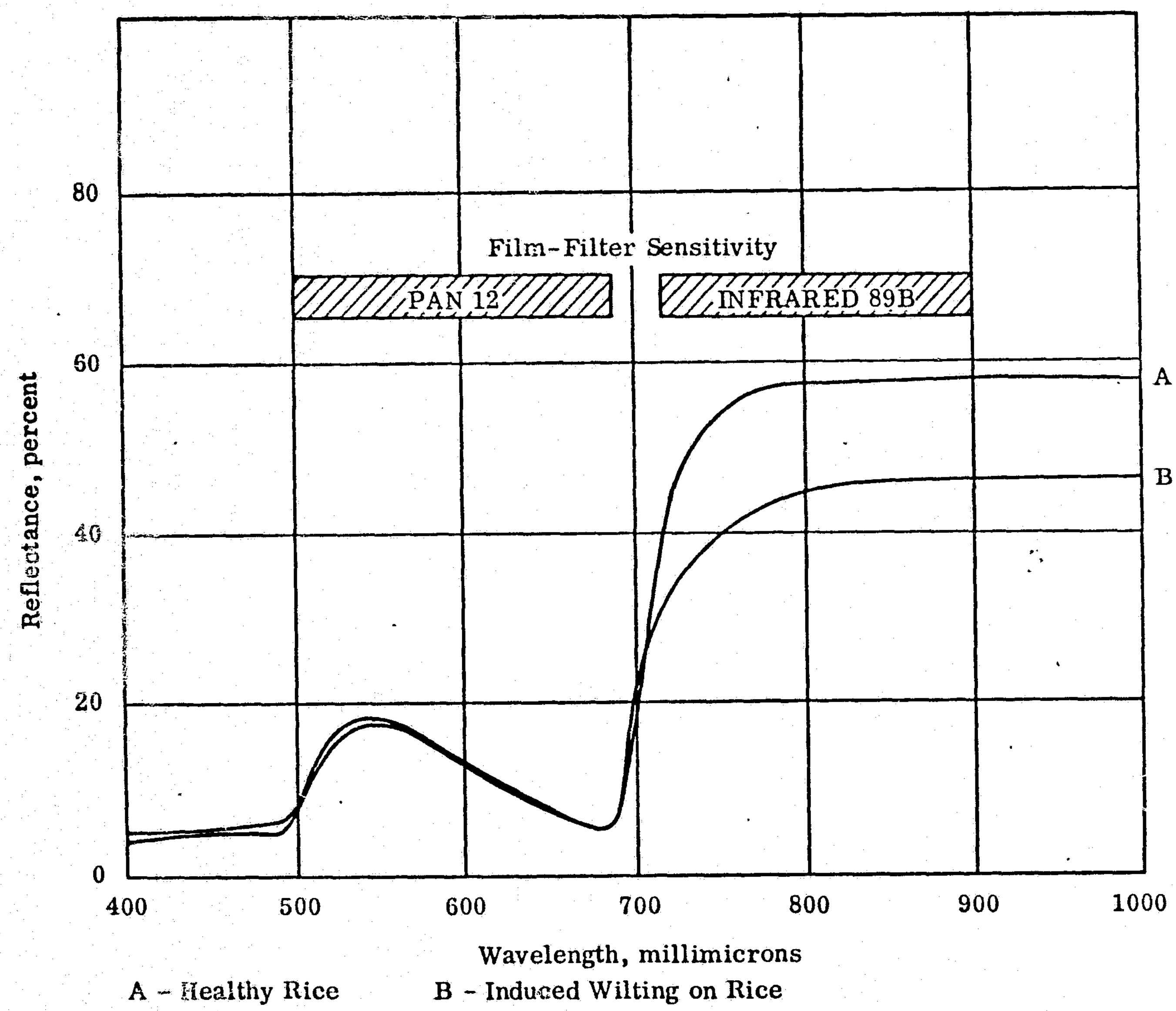


Figure 63. Spectrometric Analysis of Rice--Davis, California.

considerable accuracy from the information contained in this illustration. When a leaf becomes diseased, its spongy mesophyll (which heretofore has been turgid and highly reflective of infrared radiation) either collapses or becomes plugged by hyphae of the fungus, or both. These changes occur long before the leaf's green color starts to fade. Hence, the disease becomes detectable much sooner on infrared than on panchromatic photography, as illustrated in this diagram where the difference between curves A and B is significant in the infrared portion (700 to 900 millimicrons) of the photographic spectrum.

2.0 RICE CROP CHARACTERISTICS AND FACTORS AFFECTING YIELD

2.1 GENERAL DESCRIPTION

Rice (*Oryza sativa*) is the principal food crop of about one-half of the population of the world. Probably 92 percent or more of the world rice crop is produced and consumed in Monsoon Asia. This area extends across southeastern Asia from India to Japan and includes practically all of the adjacent tropical or subtropical islands. Nearly one-third of the cultivated area in India is planted to rice. Worldwide (other than U.S.), the range of average per acre yield of rice varies from about 1,100 pounds in India, Burma, Thailand, and Indochina to about 4,700 pounds in Spain and Italy. The average per acre yield in the United States in 1960 and 1961 was 3,400 pounds, while the worldwide average was 1,750 pounds/acre. Rice yields in Japan average from 50 to 200 percent more than in other Asiatic countries due mainly to the heavy use in Japan of commercial fertilizers, and to the development there of improved

varieties, and efficient cultural practices. In India, more than 75 percent of the area is without irrigation facilities, thus being subject to the variabilities of the monsoon rains. The need for rice is so great in India that much of it is grown on unsuitable land. Fertilizers seldom are applied to the soil, with the result that soil productivity is stabilized at a very low level. Similar conditions prevail in other rice-producing countries of southeastern Asia. Since 1953, however, the better features of the Japanese methods of culture have been gradually adopted in India and other Asiatic countries.

Thailand, Burma, and Indochina normally supply 90 percent of the rice that moves in international trade. Other important export countries are the United States, Brazil, Italy, and Egypt.

Rice is grown in Asia from below sea level to an elevation of 8,000 feet. Most of the rice crop is grown on submerged land using intensive paddy culture methods. Often the land so used is too wet for other cereals. Paddy rice land is submerged throughout most or all of the growing season.

Cultural Practices

Rice can be grown successfully only where the mean temperature is 70°F, or above, during the entire growing season of four to six months. Rice is generally grown on flooded land in China, Japan, Egypt, Italy, and the United States. The rice field must be kept wet or submerged by natural precipitation during most of the season if good yields are to be attained.

Lowland or paddy rice is grown on land that is artificially flooded. Upland rice is grown without flooding and is entirely dependent upon

seasonal rainfall. The yields of lowland rice generally are much higher than those of upland rice because the fields are less weedy and the rice does not suffer from moisture deficiency. Lowland rice, grown under rain-fed or artificial systems of irrigation, is far more important in world trade than upland rice.

Perhaps 75 percent of the rice area of India is not flooded, except by impounded rainfall in many fields, because of inadequate irrigation development where a large area is sown to the crop. In most countries, upland rice is grown on sloping land where the impounding of water is not feasible.

Floating or deep water rices consist of varieties that have the ability to elongate the culms rapidly to keep the tops above the water surface when flooded by rapidly deepening water. Such varieties may have culms 6 to 15 feet long or even longer. Floating rices are grown in valleys subject to flooding, mostly in parts of Cambodia and Thailand, but they are also found in India and Pakistan. The rice is harvested by hand, in boats, provided it is still floating when the grain is ripe.

Rice is generally grown under continuous flooding in the United States. The fields are flooded before planting; seed is sown by airplane and the fields are kept flooded to a water depth of six to eight inches until about 30 days before harvest. On some new land or where rice has been grown several years in succession and where green manure crops have not been used, soil fertility may be inadequate. Preplant application of nitrogen, and on some soils both nitrogen and phosphorous fertilizers, often produces more vigorous seedlings. Best results

are obtained when fertilizers are applied before flooding and worked into the soil to a depth of from two to four inches. Fertilizers left on the surface will stimulate rice seedlings in their initial growth but will also encourage the growth of scum-forming algae and weeds. In other areas, rice may be grown on dry land with periodic irrigation. Weeds are problems in such areas.

A seed bed should be dry, level, clean and cloddy. A wet seed bed or one which has been worked too fine and left moist will allow weeds to get a start before a field is flooded in planting, thus providing competition for the young rice seedlings. Weeds use light, space, oxygen and nutrients, which would otherwise be available to the rice. A well-levelled field is important to weed control and in production of rice. In some fields it is not practical to have less than three-tenths of a foot fall between levels, but two-tenths of a foot has proven to be better from the standpoint of water management. If a seed bed is too rough and clods too large, much of the seed will fall between clods and be lost as the clods dissolve.

To reduce the growth of scum-forming algae all old weeds, straw stubble and cover crops should be well turned under when the seed bed is prepared.

Top quality seed is essential in high yield production of rice. First quality rice seed has the following characteristics:

a. It has high germination percentage.

b. It has high bushel weight.

c. It is free of red rice and most other weed seed.

d. It is properly identified.

Seedling blight is the only important rice disease in California. Several fungi, known as water mold, which attack the seeds and seedlings soon after planting, are the causes of seedling blight. Experimental treatment of seeds with Arasan S.F.X. or Phygon XL at a rate of eight ounces to 100 lbs. of seed has provided protection against water molds. Best results were obtained by applying the chemicals on the seed and soaking in water for two hours and then draining for 48 hours before planting.

Seeding

Rice is seeded in California during April and May. A field seeded during that period can be harvested about October 1st when conditions are best for a crop of top quality milling rice.

Temperatures are often too low before April 15th to ensure a good stand. Seeding later than May 30th is hazardous because crop losses from early fall rains and immaturity may run high.

Seeding schedules in Louisiana generally run two to four weeks ahead of those in California.

Airplane seeding of rice fields is the most common practice in the United States. Seed is presoaked to assure that it will sink quickly into place where sown. As much as 500 acres a day can be seeded by air.

Fields should be seeded as soon as flooded to prevent weeds from getting a chance to start growth ahead of the rice. If the weather is warm, weeds will take up the dissolved oxygen essential to new rice and limit stand establishment.

Small acreages can best be seeded when dry, thus permitting rice and weeds to start growth at the same time. In some areas drilling rice with a grain drill is practiced to save water by starting the crop on soil moisture.

One hundred fifty (150) lbs./acre, on a dry seed basis, is an average seeding rate. Yields do not seem to be much different if the rate varies from 125 to 200 lbs./acre. Heavier rates are better on old land where tillering is limited. Lighter rates yield well on new, fertile land. Extremely thick stands lodge more readily, but a thick stand matures and heads more uniformly than a thin stand with abundant tillering.

Generally, it is unprofitable to try to save a poor stand by reseeding or by draining and reworking the field. Seeding in the water without reworking is seldom successful because there is a lack of oxygen in the germination zone and the young plants cannot get a firm roothold in the mud and slime or compete with well-started weeds. Draining and reworking requires so much time that the harvest is usually delayed until the rainy season. Although eight to ten plants per square foot is considered a good stand, reasonably satisfactory yields have been obtained where the stand averaged from three to five plants per square foot.

Most of the rice in California is sown broadcast on the water by airplanes shortly after the fields have been flooded. This provides a means of controlling water grass and other weeds, because prompt establishment of a dense rice stand crowds them out.

In the southern United States, rice usually is sown with a grain drill, which is favorable to uniform germination. Airplanes have replaced end-gate

seeders for sowing in the water. Airplane seeding is on the increase, particularly when soil or weather conditions make it difficult to prepare a seed bed suitable for the use of a drill, or where water grass infestation is a problem.

No rice is transplanted in the United States. Experiments have shown no advantage of transplanting over direct field sowing when the weeds are controlled and the plots seeded by suitable methods.

Water Requirements

If water for flooding is not available, upland rice is grown only in humid regions having more than 40 inches of annual rainfall. Yields for upland rice are only one-third to two-thirds as high as lowland rice, even in countries with high rainfall. Many weeds thrive on wet soils that are not submerged and thus are difficult to control in upland rice fields.

Lowland or paddy rice fields are submerged during most or all of the growing period underwater to a depth of four to eight inches or more. The chief purpose of maintaining the water at such depth is to suppress weed growth. This water level is maintained during the growing season until the rice is nearly ripe. Grain yield may be greatest where the water barely covers the soil surface, but such a depth cannot be maintained in the field, and if weed growth becomes excessive, as it may under shallow water conditions, yields will be low.

For effective weed control, fields should be under an average measured depth of from six to eight inches continuously. This depth will adequately suppress water grass and several types of small sedge (wire grass) and aid in the control of rough seeded bullrush. Moreover, the rice can emerge

from the water in 18 to 25 days without lowering the water level. Except in emergencies, such as scum trouble and seedling blight, water level should not be lowered. Lowering the water to less than six inches, even for a few days, can greatly intensify the weed problem. It has been said that fiddling with the water level during stand establishment has caused many rice farmers an average loss of five sacks per acre because of the water grass brought on by shallower water.

Furthermore, six to eight inches of water provides a blanket which protects young seedlings against low, early-morning temperatures which are common in the spring. However, cold water or water low in dissolved oxygen content, is often responsible for a reduced stand. Well water or reclaimed drain water or water from a cold source will make it difficult to establish a stand at the intake end of a field.

Water below 65°F will retard growth in the first checks where it has not had time to warm up and has a tendency to retard emergence in lower checks. The temperature can be raised by spreading the water in a warming basin before it enters the field. A basin 6 to 12 inches deep with an area of two percent of the field area to be served is sufficiently large.

Water low in dissolved oxygen, which is essential to young plants, may be increased in oxygen content simply. Any type of agitation, such as a series of ripples before the water enters the field, will increase the oxygen content. This is beneficial to the stand on the upper end of the field. Usually, after the first one or two checks water has absorbed adequate oxygen.

Cropping Practices

Single cropping (one crop of rice in one year) is the common practice in northern Japan and other cool temperate regions. Double or even triple cropping to rice often prevails in the warmer climates when ample water is available. Some rotations with other crops also are followed.

Much of the lowland rice in the warmer parts of southeast Asia is grown continuously; often two or three crops a year on the same land. Upland rice usually is grown in rotation with other crops because soil fertility is more critical and weed control more of a problem.

Sometimes rice culture alternates with fish culture in the submerged fields. This procedures conserves, and presumably increases, the productivity of the soil. This practice requires supplemental ponds, tanks, or streams into which the fish can be moved when the rice field is drained. Fish are grown with rice principally in Japan and China.

Fertilizers

Most of the tropical rice soils are deficient in nitrogen and organic matter, but some soils, particularly in Thailand and Burma, also are deficient in phosphorus. Rice yields in tropical areas usually are stabilized at a rather low level because of infertile soils. Animal manures, compost, and green manures are used to a considerable extent throughout southeast Asia as well as elsewhere. Commercial fertilizers are not generally applied to much of the rice crop in Asia, except in Japan, Korea and Taiwan.

Seeding Practices

Upland rice is almost always grown by direct seeding. Lowland rice is grown by direct seeding in many countries and it is the common practice

in the rain-fed culture in southeast Asia, particularly where the land is poor, or the water supply uncertain.

The transplanting method, widely practiced in Japan, involves sowing rice in small nursery seed beds with subsequent transplanting to the regular paddy field. Seeding in the seed beds usually is done from 30 to 50 days before transplanting to permit the seedlings to attain a height of 7 to 12 inches, suitable for transplanting. Most of the paddy rice in southeastern Asia and much of that in Europe and Africa is grown from transplanting. Yields often are higher, chiefly because of better weed control.

Harvest

In most of the Asiatic countries, rice is harvested with hand sickle and tied in bundles with one to two feet of straw usually being cut with the panicles. Straw may be either left in the field for plowing under or burning, or stacked for drying and used elsewhere. Threshing of rice in southeast Asia is generally done by hand or by crude mechanical threshers. Threshing often is done on threshing floors. In some areas, farm animals or humans tread out the grain.

The hand methods just described may require up to 160 hours of man labor to harvest and thresh an acre of rice. With large mechanized equipment, an acre of rice can be harvested, threshed, hauled, and dried with three hours of man labor.

Mineral Nutrition

Nitrogen is the element most often required in chemical applications to produce high yields of rice. Increases in plant height, grain and

straw yield, and number of heads usually are proportional to the amount of nitrogen added.

Controlled experiments in India indicate that the yields of rice are consistently higher where algae are present. A considerable increase in nitrogen occurs in fields in which algae grow abundantly.

The rice plant absorbs considerable quantitites of other minerals. It is important in rice production to ensure availability of these other minerals, such as phosporus, potash, calcium, iron, and manganese.

2.2 PESTS

Scavenger Beetles and Tadpole Shrimp

Scavenger beetles and tadpole shrimp damage rice fields in three ways:

a. Chewing or cutting leaves, stems and roots of the rice plants before they have emerged from the water.

b. Digging in the muddy silt and dislodging plants which float to the surface.

c. Keeping the water muddy which excludes the light and results in weakened plants.

Both pests can be easily controlled, if they are found in damaging numbers, by aerial spray application of one-and-one-half to two pounds of technical DDT per acre. In fields where these pests have caused damage in past years, a preflooding application of DDT (three to four pounds of 50 percent wettable powder) will prevent further depredations.

Pest damage to rice plants in California most frequently occurs during the first two months of the growing season. Pests may be responsible for a reduction in plant stand from April to June, but their activity is greatly reduced or of little consequence by early July. The rice water weevil, presently limited to the northern rice growing counties in California, will feed on the rice plants during the entire growing season. This weevil very seldom causes a loss of plant stand, but the feeding of the young on the roots may stunt the plant and reduce the yield if the larvae are abundant.

Triops longicaudatus

The crustacean, Triops longicaudatus (LeConte) was given the name "Tadpole Shrimp" because of its similarity to the true tadpole in color, size, and swimming activity. The shrimp hatch from minute reddish-orange eggs and pass through a series of stages until maturity, at which time they may be two inches long. These are first seen in rice fields one to two weeks following flooding.

Tadpole shrimp, in their early stages of growth, are frequently confused with a small bi-valve crustacean sometimes called a clam shrimp or rice-field clam. These clam shrimp are about twice the size of a rice seed and are frequently present in large numbers but do not damage the rice. Young tadpole shrimp feed on the organic content of the mud and small organisms. As they grow larger, their food and foraging habits change and a high population may be a serious problem to the rice grower. Small, submerged rice seedlings are delicately rooted and often coated with minute gas bubbles. The shrimp may easily dislodge these seedlings by burrowing in the mud, and by chewing the leaves and roots. The dis-

lodged plants generally float to the surface and wind movement scatters them along the rice field levees. Windrows of rice seedlings along the shoreline can also be the result of an improperly prepared seed bed. If shrimp are responsible, the uprooted seedlings will frequently show some evidence of the leaves being chewed or broken off. A rice field with continuous muddy water is generally a reliable indicator, although not positive proof, of a shrimp infestation. A maximum reduction of 25 percent of the stand occurred when the shrimp population was eight per square foot. However, there was no significant reduction in yield of grain recovered at this plant population and shrimp level. The loss of plant stand was apparently compensated by increased plant size and more heads of grain per plant.

Rice Leaf Miner

This small fly, *Hydrellia griseola* (Fallen), has been known to be present in California rice fields since 1922. The weather conditions occurring in 1953 favored its buildup and required extensive control measures. The adult females lay their small white eggs predominantly on rice plants that have emerged and are lying on the water surface. The eggs hatch in three to five days, and the larvae mine the leaf tissue between the external layers for two to three weeks before they pupate. More than one larva may be mining a single leaf and the larvae may transfer from one leaf to another after they consume the tissue of the plant they were previously mining. The miner's presence on the leaf is indicated by a blotched, greenish-brown appearance.

The damage caused by the larvae is dependent on the number that mine a single plant, and the length of time that mining is continued in the plant. Conditions that retard or prevent rice blades from obtaining a vertical position after emergence and thus increase susceptibility of attack from the miner include: (a) low air or water temperatures and unfertile soil, resulting in weakened plants and slow growth, (b) heavy wind movement by direct force, wave action, or by forcing algal growth over floating rice blades, (c) permanent excessive deep water or mismanagement of water by increasing its height too fast after an initial drop, and (d) heavy algal growth will occasionally break loose from underwater substrata and form large floating blankets that will stick to floating rice blades and prevent their rising or hinder new growth from breaking through.

These four factors all are detrimental to plant growth and favor continued activity of the rice miner and formation of algae. The best measure of the seriousness of an attack on rice is the extent and intensity of activity on the newest plant growth. The first one or two rice blades that are above water may be mined without killing the plant and growth is allowed to continue, although it undoubtedly weakens the plant and may delay maturity. If conditions are such that the new growth is continually mined, then the plant dies because of interruption of nutritional and respiratory functions. Two to three generations may occur on rice, but the second and third generations are considerably smaller, limited to cooler sections of fields and are generally heavily parasitized.

Rice Water Weevil

This insect pest, *Lissorhoptrus oryzophilus* (Kuschel), was first brought to the attention of California rice growers in August 1959. At

that time, it was limited to a 400-square-mile area in Butte, Glenn, and Yuba Counties, but has spread to Colusa, Sutter and Sacramento Counties.

The adults emerge from hibernation in April and May and begin feeding on the leaves of newly emerged rice, or they may feed on the numerous grasses associated with irrigation water. The feeding of the adult appears as a very characteristic rectangular slit on the upper surface and parallels the veins of the leaf. If this adult feeding is very extensive on young seedlings, it may kill them, but generally the weevil does not occur in sufficient numbers to reduce the plant stand. The weevils (only females have been found in this state) crawl down the plant stands below the water surface and oviposit.

The eggs are predominantly found in the leaf tissue above the crown or occasionally in the roots. The larvae emerge from the eggs in 10 to 12 days and spend this stage of their life cycle feeding on the plant roots.

If these larvae, sometimes called root maggots, are numerous, the roots will be pruned, plants will become stunted, fewer tillers will be produced and consequently less grain. Pupation occurs on roots in oval cells lined with mud.

A study was conducted at the Rice Experiment Station, Biggs, California, using three-foot-square cages and controlled populations of adult weevils to determine the extent of damage to rice flooded continuously in six inches of water. The results of these studies showed a maximum reduction in yield of grain of 32 percent when the ratio of weevils to plants was one to one. No significant reduction in plants occurred in this test.

The over-wintering generation of weevils lives until the latter part of June and is most frequently found feeding and ovipositing at the margins of the fields. The new generation of adults can be found on rice plants from July to October, but exhibits a more uniform infestation throughout the field. Studies are currently under way to determine the effect of the second generation of weevils on the rice plants. No chemical controls are presently recommended for root maggots as the weevil populations are considered to be below the economical level. Studies in progress show a preplant soil treatment to be the most effective control method for rice cultural practices of continuous flooding.

2.3 WEEDS

Rice is grown under conditions very favorable for the growth and reproduction of aquatic and semi-aquatic weeds. Most weeds that infest rice produce an abundance of viable seed, and once the soil is infested their removal is difficult. The best approach to weed control in rice is to prevent weed infestations. This may be accomplished by seeding weed-free rice seed and removing weed seedlings from the field before they produce seed. However, after the soil becomes infested with weeds, they may be effectively and economically controlled by using certain cultural and chemical methods.

Weeds compete with rice for light, nutrients, water and space. If not controlled adequately, they reduce yields and lower the market value of the crop by reducing its quality. Weeds also increase harvesting and drying problems.

Barnyard grass (Echinochloa sp.) is a serious problem throughout the rice growing areas of the United States. Yields of rice may be reduced one-fourth to one-half or even more by barnyard grass. Each year yields are reduced significantly by barnyard grass on one-fourth to one-third of the total rice acreage in Arkansas. In Arkansas, Isopropyl carbamate (CIPC) used to control barnyard grass, resulted in increased rice yields. An average net gain of $76/acre was realized in ten experiments from 1955 to 1959.

The average rice acreage in California was about 250,000 acres during that same period and the price of rice averaged about $4/100 lbs. It is estimated that barnyard grass reduces the yield of rice in California about 1,250,000 bags per year, an annual loss of $5,000,000. Comparable losses in Arkansas, Louisiana, and Texas costs the United States Rice Industry as much as $21 million annually.

Certain broadleaf weeds, such as coffee weed, curly indigo, and Mexican weed, reduce the value of rice by lowering the quality of the crop. Mud Plantain, a serious aquatic weed, has reduced rice yields by 18 to 48 percent when allowed to compete with rice for the four weeks after seeding.

Cultural methods to control weeds in rice are the predominant methods employed by rice growers in the United States. Adequate seed bed preparation combined with judicious use of water is vital in a weed control program. In addition, supplemental use of herbicides can greatly increase the effectiveness of cultural methods.

Cultural Methods of Weed Control

Properly managed rotations play an important role in controlling weeds in rice. Rotation such as rice-pasture in Louisiana and Texas, or rice-soybeans-oats in Arkansas, can effectively reduce weed competition in rice. The entire rotation must be kept weed free to obtain the maximum benefits during the rice year. For example, in a rice-soybeans-oats rotation, the soybeans may be kept weed free by proper cultivation and fallowing the oats, which should be kept free of broadleaf weeds with 2,4 Dichlorophenoxyacetic acid (2,4-D) or 2-Methyl-4-Chloro Phenoxyacetic acid (MCPA), the land may be summer fallowed to rid the field of several weed crops. A rotation which includes summer or fall plowing with several discing operations timed to kill weed seedlings is an important step in producing clean rice. Although in Louisiana and Texas a rice-pasture rotation keeps down many weed species, it is not satisfactory in controlling barnyard grass species. At present the use of clean seed, coupled with proper implementation of rotation and hand-pulling is the principal means of controlling red rice.

Repeated cultivations in the spring at one-to-three-week intervals prior to seeding rice usually reduces barnyard grass and other weed infestations. The last cultivation is usually shallow so that viable weed seed will not be brought near the surface of the soil. Seeding the rice on a roughly prepared seed bed to discourage germination of weed seed is employed in many instances. Timing of application of phosphate and nitrogen in fields of rice is also important because these nutrients stimulate the growth of barnyard grass and other weeds when applied before

seeding rice in a dry seed bed. When weed grass infestations are high, yields of rice have almost doubled by delaying nitrogen application until heading of the barnyard grass.

Chemical Methods of Weed Control

Chemical control of broadleaf weeds in rice began with the advent of 2.4-D. It has been estimated that 40 to 60 percent of the U.S. rice crop is being sprayed each year with herbicides.

A method of controlling weed grasses in southeastern rice producing areas involving the use of CIPC in combination with several cultural management practices has been developed. The combination of herbicide-cultural practice was used to control barnyard grass and other weed grasses on more than 5,000 acres of commercially grown rice in 1959. In the western rice producing area, CIPC and EPTC, in combination with various cultural practices, have shown experimental promise for the control of barnyard grass and other weed grasses.

Water grass remains the most important single weed in rice production, however, and it will be in the foreseeable future because of its adaptation to a wide range of crops and in non-crop areas. Chemical means of eradication as they become available may not be used by everyone because of the desirability of water grass as a feed for game birds. Water grass is a major weed in most irrigated summer crops and seeds remain viable for several years in non-irrigated soils. This means rotations offer no easy solution to water grass problems and it is necessary to consider control of water grass during the crop season.

One efficient and economical means of water grass control available at the present time is the proper management of water depth during the rice growing season. A minimum of six inches and a maximum of nine inches of water should be maintained for a period of at least three weeks after planting. These depths are the extremes of fluctuation between which weed control and rice production are possible. They are not the averages of fluctuating levels. This management demands level fields, accurate contours, well-constructed levees, adequate water supply, adequate drainage capacity, and an alert, capable irrigator.

The herbicide "propanil" is recommended in application in grassy fields between three to five weeks after planting. Well-timed applications of propanil have also been helpful in controlling a number of the broad-leaved weeds if they are in the seedling stage. One disadvantage of propanil is that some grass plants may be under water at the time of application and thus only partial control is obtained. Another disadvantage is that propanil has no pre-emergence activity so that if water is removed from the field at application, and held off for a period of time, additional seeds will germinate and a new growth of water grass will develop. To overcome this disadvantage, it is best not to completely drain the field. Propanil's advantage is that it can be used as a post-emergence herbicide after the infestation is apparent. This approach supposes that the procedures of rice production currently in use are satisfactory and the use of propanil is justified economically after the control by water fails. To fully exploit chemical weed control, however, it will be necessary to investigate ways of increasing yields or decreasing production costs and risks.

2.4 RICE DISEASES

Southern rice growers lose a substantial part of their crop every year because of rice diseases. In the four leading rice producing states of the south--Texas, Louisiana, Arkansas, and Mississippi--diseases reduce the average annual yield by about 5 percent. This means an annual loss of more than 100,000 tons of grain. Similar percentages of the annual yield are lost through diseases in states that grow rice in smaller acreages including Missouri, Florida and South Carolina. In California, where much rice is grown, natural conditions are so favorable to this crop that its diseases have very little effect on farming income.

Principal Rice Diseases

Seedling Blight. Seedling blight causes the stands of rice to be spotty, irregular, and thin from the time they are established. This results from the activities of various kinds of fungi, most of which grow on the kernels or hulls of seed rice or on soil particles. These fungi enter the germinating rice seed or the young seedling and either kill or injure it. If blighted seedlings emerge from the soil at all, they are likely to die soon thereafter. Those that survive are generally weak and yellowish.

How widespread and severe blight becomes in a field of rice depends chiefly on three things: (a) what percentage of the seed are infested by blight fungi, (b) the soil temperatures, and (c) the soil moisture content. Seedling blight is more severe on rice that has been seeded early, when the soil was cool and damp. (In Texas and Louisiana, the early seeding is late February and March.) This disadvantage of early seeding can be partly

overcome by planting at a shallow depth. Conditions that tend to delay the seedlings' emergence from the soil often favor seedling blight.

The fungus that causes brown leaf spot also is one of the chief causes of seedling blight. A seedling attacked by this fungus shows dark areas on the basal parts of the first leaf.

Some blights that affect rice seedlings at the time of germination can be controlled by treating the seed with chemicals. An experimental seed treatment has sometimes doubled the density of the stand obtained.

White Tip. White tip is caused by a nematode, or eel worm, which is too small to be seen without a microscope. The tips of the affected leaves turn white and later become frayed and dark colored. Parts of the leaf other than the tip also may show light color or white areas. The symptoms become most conspicuous, particularly on the flag leaf (the top leaf), just before heading. Often the flag leaf blade and sheath are twisted so that the head is held within the boot. Severely affected plants have stunted heads that produce few grains, and these grains are often abnormal in shape. The nematodes that cause white tip are carried on the seed and can attack a rice crop wherever the infested seed is sown. These nematodes do not live in the soil over the winter. During the growing season, they may be carried by flood water from one field to another. Those found on mature rice seed are either in the inner hull surface or on the kernel. None get inside the kernel. The nematodes remain dormant during the months between harvest and seedling. When an infested seed is sown in warm, moist soil, the nematodes on it become active, and when the seed is germinated they move into the growing point of the young rice plant. There they feed

and rapidly increase in numbers. Their feeding on the young leaf or on the developing head in the boot results in the symptoms described above. At the heading stage the nematodes establish themselves inside the rice flower, and there they remain during the period of grain formation. As the grain matures they become inactive. Dormant nematodes may remain alive on rough rice in storage for two years.

Commercial rice varieties differ greatly in resistance to white tip. The disease can be controlled simply by growing only varieties known to be resistant. The principal precaution needed is to avoid use of irrigation water that has passed through a field infested with nematodes assuming planting of a clean lot of seed.

Straight Head. In straight head, rice heads remain upright at maturity because the few grains formed are too light to cause bending of the panicles in the normal fashion. The diseased heads often contain no fertile seed. Usually the hulls are distorted into a crescent or parrot beak form. This distortion is especially conspicuous in the long grain varieties. One or both of the hulls may be missing. Affected plants continue to grow, have a green color darker than normal, and frequently produce shoots from the lower nodes.

Apparently straight head results chiefly from some abnormal soil condition that develops around the roots of the rice plant after several weeks' flooding. In many instances it has occurred when the soil contained much undecayed plant material from lespedeza and other crops that have been plowed under. On limited areas it has been caused by arsenic that has accumulated in the soil as a result of repeated application.

Brown Leaf Spot. Brown leaf spot is one of the more prevalent and serious rice diseases, particularly in Texas and Western Louisiana. The fungus causing it attacks the seedlings and also the leaves and necks of older plants, the hulls, and the kernels. (The word neck is applied here to the part of the rice stem just below the head.) The fungus is seed-borne. It is probable that it also lives from one crop to the next on old rice straw in the soil.

Leaf spots may be evident from shortly after the seedling emerges until the plant matures. They are circular or oval and are of dark brown or grayish color. The spots vary in size, color and appearance according to rice variety. Severe leaf spotting is often shown by plants in dense stands and by other weak plants. On severely affected plants the leaves, or large parts of them, die before maturity and the disease may reduce the yield and the quality of the grain.

When the brown leaf spot fungus invades the neck or branches of the head it causes a condition known as "Rotten Neck," which is similar to one caused by Blast (the disease discussed next). A plant thus affected has lightweight or chalky kernels. Spots very similar to those on the leaves appear on the hulls and persist after the seed matures. Spots or stained areas may occur also on the kernels, reducing the quality of the grain.

If rice has been protected by seed treatment from seedling blight caused by the fungus that causes brown spot, it can still become infected with this fungus when it is grown beyond the seedling stage.

No rice variety is considered resistant. Damage from brown spot can be lessened by maintaining good growing conditions for rice through balanced fertilizing, crop rotation on land leveling, thorough soil preparation, and other good cultural practices.

Rice Blast Disease. Blast disease in rice is caused by a fungus which produces symptoms such as spotting on the leaves and blighting of the leaves or the whole plant. Rice plants probably are most susceptible to leaf attack before irrigation begins and at the tillering stage. In severe cases, the plant is stunted and loses nearly all its leaves or the whole plant, including the tillers, is killed. Blast fungus frequently attacks the neck, blighting the head; the name "rotten neck" is applied to breaking over of the head at the affected neck region. In addition, the fungus attacks the nodes of the stem, with the result that they turn dark and the part of the stem above the point of attack is killed.

Rice is more susceptible to attack by blast when grown on soils having a high nitrogen content. Rain and warm weather favor development of blast; therefore, rice sown in June in Louisiana is more susceptible to attack by blast than earlier-planted rice. When young plants are attacked, and irrigation has been withheld, development of the disease can be retarded by flooding the field.

It is not possible to estimate the amount of blast disease that will occur in any area by reference to information on disease occurrence during previous years. The factors which influence the occurrence and

spread of blast disease such as weather conditions, planting date, growing techniques, and susceptibility of the rice variety grown, can be used as indicators of the possible occurrence of blast disease in a particular growing area, if such information is available either from ground sources or photo interpretation or a combination of the two.

As previously indicated, there are two stages of rice blast disease: the leaf blast stage and the rotten neck stage. The leaf stage is associated with blighting of the leaves and a blasting of the head or panicle. Both stages are merely different symptoms of the ancient disease of rice known as "blast."

The blast disease has caused losses in yield in Louisiana periodically for many years, and since 1955 has become quite prevalent in southwest Louisiana where in 1959, for example, losses of 30 to 40 percent were encountered in some fields due to the effects of this disease.

The <u>leaves</u> of the rice plants are susceptible to infection by the causal fungus from the seedling to the late tillering stage of growth. By heading time they are less susceptible, but the tender <u>panicles</u> then are subject to attack. The fungus invades the "neck" or top internode and the node at the base of the panicle, and frequently the branches of the panicle. These changes in relative susceptibility by growth stages, along with the rather seasonal occurrence of conditions favoring spread and infection, present problems in detecting the presence of the disease in fields by aerial photography, particularly in comparing conditions in one year with those in another, or in one field with those in another. However, it is possible to detect the effects of the fungus attacks on the

leaves of rice plants given sequential photography to determine possible yield reductions caused by the disease in light of other crop factors.

The rotten neck stage is more difficult to detect on small-scale photography, particularly in the presence of earlier infection of the same areas by leaf blast.

Narrow Brown Leaf Spot. Narrow brown leaf spot, sometimes known as cercospora, is perhaps the most prevalent disease of rice in the Gulf States. This disease varies in severity from year to year. Generally, it becomes more severe as the rice reaches maturity. The leaf spots are long and narrow and are a light brown or brown color. In severe cases the leaves die, one after another, until hardly any remain. Infection does not become very severe until late August or September. Therefore, early-maturing varieties tend to escape heavy infection if they are sown early.

Marked differences in susceptibility have been found among rice varieties. However, some of the different races of the fungus causing that disease may damage certain rice varieties that are resistant to other races. Because the prevalence of individual races varies from year to year in relation to that of other races, a rice variety may show resistance to narrow brown leaf spot in a certain place for several years and then succumb to it.

Stem Rot. Stem rot, caused by a fungus that lives in the soil, is one of the more important rice diseases in Arkansas and Louisiana, and one of the less important in Texas. It has been found in California. The first symptom is the appearance of irregular-shaped, water-soaked areas

on the sheaths, at or slightly above the water line. Gradually these areas turn black and become larger and, in the course of time, infection enters the stalks. At this stage dark masses of fungus growth develop together with black or dark-brown streaks along the stalk. In more advanced stages, splitting the stalk reveals a more cottony grayish mold inside. Later, when the rice is generally approaching maturity, many small black seedlike bodies, called sclerotia, can be seen within split stalks and in the rotting sheaths. At this stage the stalks break over and the plants lodge. Plants that are attacked early and killed before they mature produce lightweight grain or almost no grain. Lodging resulting from stem rot often makes harvesting difficult (not all lodging of rice is due to stem rot).

The fungus-causing stem rot often develops abundantly in rice stubble after harvest, even if little stem rot was present when the crop matured. Fungus lives in the soil and stubble in the form of sclerotia and may remain alive in the soil for six years. Certain wild grasses are susceptible to stem rot. The infection may spread to rice. None of the commercial varieties of rice are highly resistent to stem rot. Because stem rot generally does not become prevalent until August or September, early-maturing varieties tend to escape serious damage if sown early.

Tests and observations made in Arkansas showed that application of potassium fertilizer to the soil reduced the severity of stem rot. Another control measure is to drain the water from the field at an early stage of sheath infection and keep the soil saturated, but not covered with

water, until the rice has almost matured. Although the fungus can live in the soil for several years, crop rotations undoubtedly have considerable value for controlling it.

Root Rot. Root rot as discussed here includes several diseases, or disease orders, in which the roots of young rice plants have become deformed and discolored, then decay. As root decay progresses, the leaves cease to grow normally and turn yellow. The affected plants may die at any stage of growth. Root rot may be caused by any one of several fungi. Rice roots may be damaged also, by the feeding of nematodes and of root maggots. Plants growing in saline or alkali spots generally are affected with root rot and as a result grow poorly.

Minor Rice Diseases

Bordered Sheath Spot. A fungus, which is a minor rice disease, frequently is found in Louisiana and Texas. Large spots appear on the sheaths just above the water line and occasionally on the lower leaves. The spots have irregular outlines and reddish-brown borders. Generally, the disease is observed on only a low percentage of the rice plants in the field and in only a limited part of the field. It is favored by warm, moist weather. Generally, the plants attacked are in thick stands that retain moisture a large part of the day and are in the late tillering stage. Only slight losses result, because the few plants affected are not often damaged severely. Various wild grasses growing in mixture with rice may serve as sources of the infection. No control measures are known or warranted.

Leaf Smut. Leaf smut is a minor fungus disease of rice in which small, slightly raised black spots, called sori, develop on the leaves and, to a lesser extent, on the sheaths and stalks. These spots contain the black spores of smut fungus. Often infection is heavy enough to kill the tips of the leaves. When the spores have matured, the sori break open and liberate them. Leaf smut appears rather late in August or in September. No control measures are warranted.

Kernel Smut. Kernel smut, another fungus disease of rice that has caused minor losses in the south, can be detected on the heads that have almost matured. At that stage, a part or all of the starchy material of each affected kernel has been replaced by a black mass of smut spores. Release of some of the smut spores within causes discoloration of the hulls. Generally, only two to eight smutted kernels are found on a head.

The smut is detected most easily after rain or in early morning after a heavy dew. Moisture causes the dark mass of spores to swell and break out between or through the hulls. Spores that have not yet broken out can be seen through the wet hulls.

Kernel smut does not destroy the rice embryo, and the diseased seed generally germinates even if all the endosperm has been replaced by smut spores.

Because the life history of the kernel smut fungus is not fully understood, no control suggestions can be given. Varieties of rice seem to differ in susceptibility, but reliable information on resistance is lacking. Early sown varieties generally show little or no smut.

Kernel Spots. Several types of kernel spots are found on rice. Many fungi cause rice kernels to be spotted, stained, or otherwise imperfect. Generally, the same fungi cause heavy spotting or discoloration of the hulls. Kernel spotting appears to increase in damp or rainy, warm weather. Punctures of the developing kernel by the rice stink bug, plus growth of fungi in the injured areas, result in the type of kernel spot called pecky rice. The presence of spotted or stained kernels reduces the grade of rice. Also, kernels that are severely spotted and therefore chalky break into pieces in the milling process. Thus, kernel spot reduces yield of head rice. At present no control method can be recommended.

Hoja Blanca. Hoja Blanca, a rice disease caused by a virus that is spread by a plant hopper, is a relatively new disease of rice plants, now posing a formidable threat to the United States rice crop. In 1959, this virus disease launched its first direct attack in one of our major rice growing areas in Louisiana. The insect that spreads the disease (Plant hopper, *Sogata orizicola*) was found by Federal/State surveys in 14 Louisiana parishes, and the disease itself in rice plants in 11 of these parishes.

Although eradication work was prompt and the season ended without real economic loss, this outcome is not reassuring. In the experience of two Latin American countries, Cuba and Venezuela, an initial outbreak of hoja blanca has foreshadowed heavy rice crop losses in following years. Awaiting the development of resistant new rice varieties, many growers in these countries have to abandon their preferred varieties, mainly American long grain rice types, and plant a few stop-gap, medium grain varieties known to have some resistance.

Hoja blanca has been spreading in tropical America since 1952 and is one of the most troublesome problems that rice growers in the Western Hemisphere have had to face. If the disease proves able to flourish in our temperate zone and under our farming conditions, as it can in the tropics, it will be a threat to our commercial rice belts--the concentrated rice plantings covering 1,500,000 acres in Louisiana, Arkansas, Mississippi, Texas, and California. All leading rice varieties grown in these states are known to be susceptible to hoja blanca.

Hoja blanca has been identified only in the Western Hemisphere. It appears to be a rice plant disease native to the Western world. When hoja blanca attracted attention in Panama in 1952, the small infestations did not show immediately how destructive the disease could be. By 1956, hoja blanca had demonstrated that it could spread swiftly and wreck rice production. That year growers in Cuba lost 25 percent of their crop; and in Venezuela, more than 50 percent. In Venezuela, the disease spread through the entire rice growing area of 75,000 acres in 90 days after its discovery.

Since the autumn of 1957, the hoja blanca virus and its insect vector have invaded three of our southern states, perhaps due to the insect riding winds in a tropical storm. First symptom of hoja blanca is appearance of one or more white stripes on a leaf blade, or whitening of an entire leaf blade, or mottling of a leaf in a typical mosaic pattern. The diseased plants do not make normal height growth. Their panicles fail to reach normal size and often remain partly inside the sheath. The hulls that enclose stamens and pistil turn brown and rapidly dry out. Often they become

distorted. The flower parts are sterile or even absent. Because the diseased plant produces few seeds or none, its head remains upright instead of bending over at maturity. Rice plants do not die as a result of hoja blanca. Normal tillers and diseased tillers may be produced by the same plant. Often the second-crop tillers of an infected plant show no symptoms.

The causative agent of the hoja blanca disease is now commonly termed the virus. A plant hopper (Sogata orizicola Muir) is commonly termed the vector. These terms suit convenience and are reasonably accurate. Actually the virus has not been isolated and used in producing hoja blanca in rice plants, which would conclusively identify a virus as the cause. However, hoja blanca is so similar to other virus-caused diseases in plants, that a virus is almost certainly the hoja blanca causative agent. As for the vector, the plant hopper S. orizicola has been the only insect proved responsible for transmitting hoja blanca, and numerous other suspect insects have been tested and ruled out. Additional insects, however, continue to be tested. Tender young rice plants are targets sought out and preferred by the hopper for feeding and egg laying. Hoja blanca symptoms have been known to appear in young rice plants as early as five days after the hopper began feeding, although a lag of two weeks is more usual.

The first signs of hoja blanca infection are yellowish spots or streaks on some emerging leaves, indicating loss of vital green chlorophyl. An emerging leaf may at first show a few spots, and the part appearing later may be nearly or completely white. Once a leaf has developed, the symptoms

may sharpen with age but the pattern will not change. That is, a leaf partly streaked and mottled will not whiten more extensively. The damage in a plant as a whole is likely to be progressive, with succeeding leaves that appear showing increasingly serious symptoms.

A plant infected when young fails to grow to normal height, florets are brownish and deformed. Panicles of the diseased plants remain upright instead of drooping in normal fashion. In recent field tests in Cuba, Agricultural Research Service scientists measured the loss in panicle weight when susceptible varieties of rice were infected at various stages by hoja blanca. The younger the plant when infected, the greater was the yield loss. Losses ranged from 386 to 1,158 lbs./acre in fields that normally yield about 3,000 lbs./acre. Total losses after milling would be even more staggering.

A rice plant, once infected with hoja blanca, is never entirely freed of the virus. When such plants put out new tillers after the primary harvest, the ratoon crop may develop badly or well, depending on the amount of the virus remaining. Some new shoots on the same plant may be diseased and some healthy.

Plant scientists who first examined hoja blanca damage in rice plants recognized a strong resemblance to stripe--a rice disease never known to cause economic damage outside of Japan, and not known to occur in the Western Hemisphere.

Stripe is a "yellows" disease, caused by a virus, carried by a plant hopper--all true of hoja blanca. It seemed possible that stripe might have reached Latin America.

But experiments have proved that different plant hoppers carry the two diseases, indicating that the viruses have different requirements and are, therefore, not the same. Experiments have shown also that rice varieties react differently to the two diseases; that is, a variety may be resistant to hoja blanca and susceptible to stripe. Moreover, plant symptoms of hoja blanca and stripe, although similar, can be distinguished. Japanese scientists who visited Cuba have pointed out that leaves of a hoja blanca-damaged plant develop normally except for the characteristic whitening; whereas, the central leaves of a stripe-damaged plant fail to unroll and tend to bend down in the shape of a sickle blade. A Japanese scientist commented that hoja blanca does not kill young rice plants as extensively as does stripe. This difference may be explained at least partly by the fact that S. orizicola infestations have been light early in the season with a buildup toward heavy population as the season advanced.

The Key Roll of the Hopper

The hoja blanca virus can destroy rice plants only when the right insect provides essential incubation, transport, and transmission into rice plant tissues. Without the insect, various experiments to produce the disease in plants have failed. Scientists have tried inoculating healthy rice plants with juices of plants infected with hoja blanca, growing rice plants from seed of infected plants, and planting in soil in which infected rice plants were grown--all without developing hoja blanca in test plants. On the other hand, they have successfully inoculated rice plants using the hopper S. orizicola as a vector. Destroying or outwitting this insect, therefore, is a main key to control of the disease.

Variety

Generally, the selection of a particular variety of rice for planting depends upon several factors, such as:

a. Maximum yield under the prevailing conditions,

b. Maximum resistance to significant diseases,

c. Resistance to cold temperatures, and lodging,

d. Availability and price of suitable seed, and

e. Consumer's preference.

It is very difficult to determine from aerial photos what variety of rice has been planted, although certain indicators of a particular variety may be detectable on the photos, such as absence of disease or lodging when nearby fields are severely damaged by these agents.

In some situations, significant color and tonal differences are due to varietal changes from one plot to the next. It is evident that unless one is aware of these varietal differences, it is possible to attribute some of these color changes mistakenly to limiting factors when in reality, the yields for these various varieties may be quite normal.

2.6 LODGING

The amount of damage (yield reduction) caused by lodging in a grain field depends upon the period in the development of the crop when the damage occurs. If the area involved is extensive and damage occurs early, before the panicles have formed or shortly after their emergence, yield reductions due to lodging can be severe. If lodging occurs at or near harvest time following complete formation of the grain, relatively minor

yield reductions occur--depending on the ability of the combine operator and his equipment to pick up the lodged grain. Where hand harvesting is practiced, yield reductions under these circumstances may be insignificant.

It was found from our grain studies that areas susceptible to lodging could be identified on aerial photography by reference to plant vigor during the early part of the growing season. Applications of excess nitrogen tend to increase the amount of foliage produced by rice plants. These high-vigor areas are typically susceptible to lodging due to the lush, succulent growth of the rice plants. When wind storms occur in areas where high rates of nitrogen have been applied, the heavy foliage tends to be blown over more frequently than does the less vigorous, less succulent foliage. Our experience suggests the following important generalization: wherever lodging has occurred, it was also possible to detect high-vigor vegetation on infrared photography taken at an earlier date; it does not follow, however, that wherever high-vigor occurs, lodging will invariably occur.

APPENDIX C

Photo Interpretation Response form for Yield Estimation. This form is used to tabulate responses of photo interpreters for each photo date and film record obtained. At the end of the season actual yield supplied by the cooperating farmers is compared with estimated yield to arrive at error figures.

Sheet No.____

PHOTO INTERPRETATION DATA
YIELD ESTIMATES

Interpreter________________

PHOTO DATA

Area____

Photo Date________________ Scale________________

Film/Filter________________ Photo Quality________________

PI DATA

Field No.									
Field Acreage, Actual									
Field Acreage, PI									
Potential Yield, tons/acre									
Field Potential, %									
Field Potential, tons/acre									
Yield % Reduction Factors, Total Effect	Disease								
	Lodging								
	Soil								
	Other								
Total Yield Reduction, %									
Net Yield, tons/acre									
Actual Yield, tons/acre									
Error in Estimate, tons/acre									
Error in Estimate, % ±									

(Use other side for calculations.)